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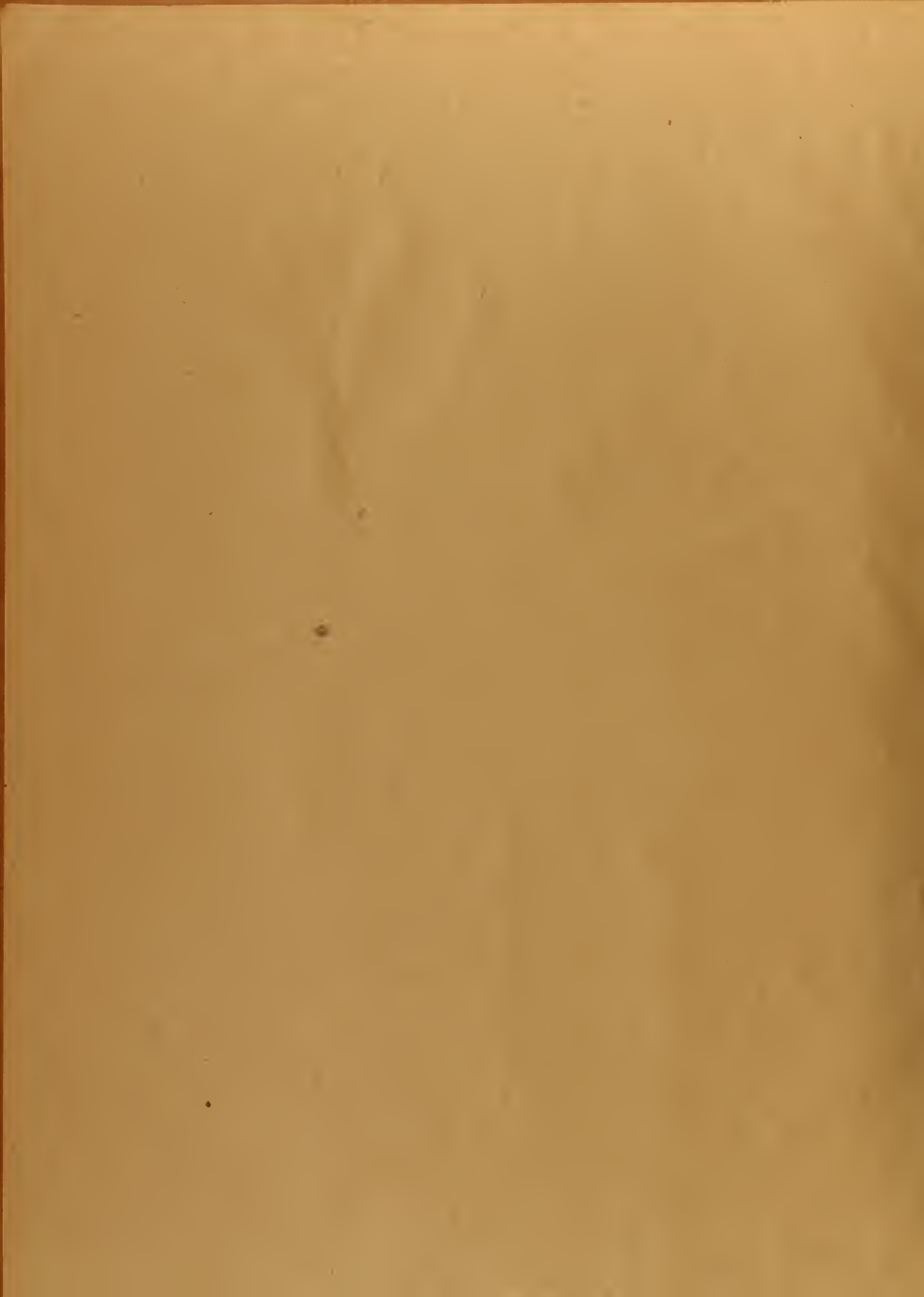
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High-Intensity, Short Duration

Light Sources

by

Robert Robinson Green

An Essay

Submitted to the Advisory Board

of

The Johns Hopkins University

in conforming with the requirements for the
Degree of Master of Engineering.

Baltimore, Maryland

May, 1949

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The photograph of the various flashlamps was very kindly supplied by the Naval Ordnance Laboratory whose personnel, especially Mr. W. T. Whelan, were most helpful in supplying much valuable information on multiple flash equipment.

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INVESTIGATION

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87	9.7	9.7	9.7
88	9.8	9.8	9.8
89	9.9	9.9	9.9
90	10.0	10.0	10.0
91	10.1	10.1	10.1
92	10.2	10.2	10.2
93	10.3	10.3	10.3
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95	10.5	10.5	10.5
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Information on circuit used for hypothesis testing

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INTRODUCTION

The subject of short duration high intensity light sources is one which has attained considerable importance in the last few years. Many problems under investigation today are being studied by the use of high speed photographic techniques in conjunction with various optical arrangements. Such transient phenomena as the flight of projectiles, flow lines in supersonic wind tunnels, flow lines in underwater impact, and others are being studied in this manner. Some of these problems can be investigated with the means now available. Some can be only partially explored. But on still others not even a good beginning can be made because the techniques are not yet far enough advanced.

In order to understand the attendant difficulties, it is necessary to consider some of the requirements in the making of very high speed photographs or shadowgraphs, and the possible solutions. First of all, of course, is a means of combining film speed and light to produce sufficient exposure in a very short time. Sufficient implies that the resulting photographs will be readable even after much enlargement. Secondly, the combination must not produce interference such as shadows or an uneven density over the photograph. Thirdly, the light source must be of the right shape

INTRODUCTION

The subject of short duration high intensity light sources is one which has attracted considerable importance in the last few years. Many problems under investigation today are being studied by the use of light from short duration light sources in conjunction with various optical arrangements. Such transient phenomena as the flight of projectiles, flow lines in supersonic wind tunnels, lines from in accelerated liquid, and others are being studied in this manner. Some of these problems can be investigated with the means now available. Some can be only partially explained. But on still others not even a good beginning can be made because the techniques are not yet far enough advanced.

In order to understand the essential difficulties, it is necessary to consider some of the requirements in the making of very high speed photographs or kymographs, and the possible solutions. First of all, of course, is a means of obtaining the speed and light to produce satisfactory exposure in a very short time. Solutions require that the resulting photographs will be readable even after some exposure. Secondly, the combination must not produce interference such as shadows or an uneven density over the photographic. Thirdly, the light source must be of the right shape

and/or size for the optical result desired. An additional requirement on the light source may be the nature of the spectrum desired. This last, in general, is not a dominant consideration. The first three are essential. In a particular problem there may be other special requirements imposed on the technique. Most of these will not be considered here.

The first requirement stated in the foregoing paragraph is the heart of the problem. As the time of the exposure gets shorter and shorter, it is obvious that either more light must reach the film, or that the film must become faster, that is, react to less light. Thus, there are basically two approaches. Considering the second approach for a moment, it can be said that advances are being made all the time in the sensitivity of film. But it is also true that unless some radical advance is made in the photographic process, such an approach shows no promise of providing more than a small part of the solution.

The other approach, then, is to raise the intensity of the incident light and to control the time it impinges on the film. This approach also offers two possible solutions. The first is to produce steady high intensity lighting and control its incidence on the film with a shutter. There are distinct advantages to such a solution, and it is under considerable study, largely in the direction of the Kerr cell. The Kerr cell is a liquid shutter whose transmission of light is controlled by the voltage impressed across it. It has been used

only for the optical results desired. In addition
regard to the light source may be the nature of the
specimen desired. This fact, in general, is not a decisive
consideration. The first factor is essential. In a certain
case it may be that special requirements are placed
on the technique. Most of these will not be considered here.
The first paragraph stated in the foregoing paragraph
in the sense of the problem. As the line of the spectrum falls
shorter and shorter, it is chosen that either more light will
pass the film, so that the film may become faster, that is,
more sensitive to less light. Thus, there are probably two requirements.
Satisfying the second requirement for a moment, it can be said
that since the film will all the time in the sensitivity
of film. But it is also true that unless some technical advance
is made in the photographic process, such an advance shows no
promise of providing more than a small part of the solution.
The second requirement, then, is to raise the intensity of
the incident light and to provide the film it requires on the
film. This movement also involves other possible solutions. The
first is to produce steady, high intensity lighting and vacuum
in the light source and the film into a vacuum. There are distinct
advantages to such a solution, and it is rather considerable
work, largely in the direction of the first will. The first
will in a light source would be a vacuum of light is pro-
vided by the vacuum improved source. It has been said

successfully in a number of experiments of a specialized nature. However, in its best present development it transmits about 45 percent of the total light when open. When shut, the cell still transmits some five percent of the total light. In addition there may be some optical distortion of small magnitude adversely affecting any photograph. A recent article by Zarem describes developments in this field.(22)

The other solution, which is the subject of this paper, is the production of a high-intensity light pulse of short duration. This, at the moment, appears to be the simplest. It has been used in more or less elementary forms for a number of years, but only recently has considerable effort been made toward refinement. Sparks of relatively low intensities and of relatively long durations have been used previously in ballistic studies. Now it is desired to get very high intensities and time durations of fractions of micro-seconds. One example will suffice. Suppose an investigation is being made of atomization in an air stream at a Mach number of two. Suppose also, that the effective duration of the light pulse from a spark gap is one micro-second in length. In one micro-second a particle travels .026 inches. On the average shadowgraph this would be a relatively short distance. If the atomized drop were .001 inches in diameter and we enlarge the shadowgraph one hundred times, the drop appears .1 inches in length, while the streak actually seen is 2.6 inches long.

... is a number of experiments of a specialized nature. However, in the past research development in this field about 45 percent of the total light was open. When shut, the cell still generates some five percent of the total light. In addition there may be some optical distortion of small magnitude adversely affecting any measurement. A recent article by James describes developments in this field. (22)

The other section, which is the subject of this paper, is the production of a high-intensity light pulse of short duration. This, at the moment, appears to be the simplest. It has been used in some of the elementary forms for a number of years, but only recently has considerable effort been made toward refinement. Reports of relatively few investigators and of relatively long duration have been used previously in particle studies. Now it is desired to get very high intensities and short durations of transitions of micro-second. The results will appear. Suppose an investigation is being made of phenomena in an air stream at a Mach number of two. Suppose first, that the effective duration of the light pulse from a spark gap is one micro-second in length. In one micro-second a particle travels 1000 inches. On the average motion across this would be a relatively short distance. If the stream had a velocity of 500 inches in diameter and we enlarge the diameter to one hundred times, the drop exposure is 1 inch in length, while the streak actually seen is 5.6 inches long.

This presentation might, if there were not too many drops, show the flow. But it shows nothing about the shape of the drop, and if there were many drops, the streaks would probably cross and recross to cause confusion. Such a light pulse is obviously not satisfactory in this case.

It will be noted that the phrase "effective duration" is used. "Effective duration" due to film characteristics may or may not be substantially the same as the picture of the time intensity function presented on the oscilloscope. The reasons for this will be discussed in detail later.

This paper is largely devoted to a report on an extensive investigation of short duration spark sources, but it will include some survey on other types of sources, namely flashlamps and lamps adapted for flashing. These, in general, have not been subject to the same sort of investigation, although they are a little easier to handle and use in some respects.

For a number of applications line sources are desired. For example, it is now proposed to investigate the boundary layer in supersonic flow using an interferometer, which would require a line source. In another case, for Schlieren optics, sources of finite shape and size (as distinguished from the spark which is almost a point source) are preferred. As will be shown, this is not practical with the spark, but may be almost attained with some of the others.

This presentation shows, it seems very not too many things, about the book. But it shows nothing about the scope of the book, and it seems very much more, the picture would not be very clear and the picture is somewhat uncertain. What is the picture is obviously not satisfactory in this case.

It will be noted that the picture "effective direction" is used. "Effective direction" has to this identification and it may not be satisfactorily the same as the picture of the time, especially, however, presented on the condition. The reason for this will be discussed in detail later.

This paper is largely devoted to a report on an extensive investigation of some of the more recent work, but it will include some survey on other types of work, namely, the investigation and design suggested for planning. There, in general, have not been enough in the same sort of investigation, although they are a little wider in range and in some respects.

For a number of investigations the picture are given. For example, it is not possible to investigate the boundary layer in aerodynamics like using an accelerometer, which would require a line sensor. In another case, the behavior of a number of finite elements and also the differential from the point which is almost a point sensor and the picture. It will be shown, this is not possible with the picture, but may be almost identical with some of the picture.

The use desired will primarily determine the choice of source. The use is a combination of so many variables that to suggest all of them is impossible. A repetitive pulse may be desired. Light for still photography of a projectile in flight may be desired. Basically, however, many of these are matters of design of power supplies and triggering. The prime difficulty in design and application at present is the lack of information about the fundamental characteristics of the light pulses to be obtained from the various sources under short duration high output conditions.

The following chapters attempt to describe in detail some of the characteristics referred to above with the intention of arriving at some general conclusions on which designs may be based. The author does not claim that his conclusions are necessarily definitive or final. For that reason a great deal of data is presented which another may be able to interpret differently and adapt to any number of conditions. In any case the information presented may serve as a guide in approaching a problem of this nature.

Table I illustrates the levels of intensity of the sources with which this paper deals.

The new design will inevitably determine the design of the system. The new is a combination of an easy, continuous flow of information and a high degree of flexibility. It is suggested that the design of the system be based on the following principles: 1. The design should be based on the needs of the user. 2. The design should be based on the needs of the system. 3. The design should be based on the needs of the organization. 4. The design should be based on the needs of the society. 5. The design should be based on the needs of the future. 6. The design should be based on the needs of the present. 7. The design should be based on the needs of the past. 8. The design should be based on the needs of the world. 9. The design should be based on the needs of the universe. 10. The design should be based on the needs of the God. 11. The design should be based on the needs of the Devil. 12. The design should be based on the needs of the Angels. 13. The design should be based on the needs of the Demons. 14. The design should be based on the needs of the Saints. 15. The design should be based on the needs of the Sinners. 16. The design should be based on the needs of the Holy. 17. The design should be based on the needs of the Unholy. 18. The design should be based on the needs of the Good. 19. The design should be based on the needs of the Evil. 20. The design should be based on the needs of the Light. 21. The design should be based on the needs of the Dark. 22. The design should be based on the needs of the Truth. 23. The design should be based on the needs of the Lie. 24. The design should be based on the needs of the Love. 25. The design should be based on the needs of the Hate. 26. The design should be based on the needs of the Mercy. 27. The design should be based on the needs of the Cruelty. 28. The design should be based on the needs of the Kindness. 29. The design should be based on the needs of the Unkindness. 30. The design should be based on the needs of the Generosity. 31. The design should be based on the needs of the Greed. 32. The design should be based on the needs of the Humility. 33. The design should be based on the needs of the Pride. 34. The design should be based on the needs of the Modesty. 35. The design should be based on the needs of the Immodesty. 36. The design should be based on the needs of the Simplicity. 37. The design should be based on the needs of the Complexity. 38. The design should be based on the needs of the Clarity. 39. The design should be based on the needs of the Obscurity. 40. The design should be based on the needs of the Brightness. 41. The design should be based on the needs of the Darkness. 42. The design should be based on the needs of the Warmth. 43. The design should be based on the needs of the Coldness. 44. The design should be based on the needs of the Softness. 45. The design should be based on the needs of the Hardness. 46. 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TABLE I
COMMON LIGHT SOURCES

Source	cp/mm ²
* Tungsten Lamps (house use)	.022 to .046
* Acetylene flame	.067
* Mercury arc	.93 to 1.55
* Tungsten filament (gas filled) (10 lumens per watt)	4.69
* Tungsten filament (900 watt movie lamp)	26.6
* Tungsten filament (10 kilo-watt lamp)	30.5
* Sun at earth's surface (calculated)	1650.
* Carbon arc crater	1425.
* Blackbody at 5000° K	840
Liebesart Gap (10,000 volts)	1854 x 10 ³
AH-6 (Mercury tube used as flashlamp)	3 x 10 ³
FT-121 (Flashlamp)	4 x 10 ³

* (First part of Table from: Light Photometry and
Illuminating Engineering, by W. E. Barrows, McGraw-
Hill, Inc.)

Last three sources are short duration source values of
intrinsic brilliance obtained experimentally.

COMMON LIST NUMBER

DATE	DESCRIPTION	AMOUNT
1954	* Transfer from (Common Fund)	100.00
1955	* Additional from	100.00
1956	* Transfer from (Common Fund)	100.00
1957	* Transfer from (Common Fund)	100.00
1958	* Transfer from (Common Fund)	100.00
1959	* Transfer from (Common Fund)	100.00
1960	* Transfer from (Common Fund)	100.00
1961	* Transfer from (Common Fund)	100.00
1962	* Transfer from (Common Fund)	100.00
1963	* Transfer from (Common Fund)	100.00
1964	* Transfer from (Common Fund)	100.00
1965	* Transfer from (Common Fund)	100.00
1966	* Transfer from (Common Fund)	100.00
1967	* Transfer from (Common Fund)	100.00
1968	* Transfer from (Common Fund)	100.00
1969	* Transfer from (Common Fund)	100.00
1970	* Transfer from (Common Fund)	100.00
1971	* Transfer from (Common Fund)	100.00
1972	* Transfer from (Common Fund)	100.00
1973	* Transfer from (Common Fund)	100.00
1974	* Transfer from (Common Fund)	100.00
1975	* Transfer from (Common Fund)	100.00
1976	* Transfer from (Common Fund)	100.00
1977	* Transfer from (Common Fund)	100.00
1978	* Transfer from (Common Fund)	100.00
1979	* Transfer from (Common Fund)	100.00
1980	* Transfer from (Common Fund)	100.00
1981	* Transfer from (Common Fund)	100.00
1982	* Transfer from (Common Fund)	100.00
1983	* Transfer from (Common Fund)	100.00
1984	* Transfer from (Common Fund)	100.00
1985	* Transfer from (Common Fund)	100.00
1986	* Transfer from (Common Fund)	100.00
1987	* Transfer from (Common Fund)	100.00
1988	* Transfer from (Common Fund)	100.00
1989	* Transfer from (Common Fund)	100.00
1990	* Transfer from (Common Fund)	100.00
1991	* Transfer from (Common Fund)	100.00
1992	* Transfer from (Common Fund)	100.00
1993	* Transfer from (Common Fund)	100.00
1994	* Transfer from (Common Fund)	100.00
1995	* Transfer from (Common Fund)	100.00
1996	* Transfer from (Common Fund)	100.00
1997	* Transfer from (Common Fund)	100.00
1998	* Transfer from (Common Fund)	100.00
1999	* Transfer from (Common Fund)	100.00
2000	* Transfer from (Common Fund)	100.00

CHAPTER I

THE LIEBESSART GAP

There are numbers of sources which can, or conceivably could provide short duration high-intensity light pulses. However, this investigation was originally undertaken primarily from the point of view of making shadowgraphs in wind tunnels. For this purpose the spark gap is the most widely used.

The type of spark gap investigated here is of a rather special nature. Known as the Liebessart gap, it was introduced in this country by General (then Colonel) Paul Liebessart of the French Army who suggested it to the Ballistics Research Laboratories at Aberdeen. Presumably he was acquainted with some of the properties of this gap, but exactly how much is not known in this country. Certainly the information available to the above institution was not extensive. The Liebessart gap is an enclosed gap in air as illustrated in Figure I.

It is essentially a pressurized gap. The insulator enclosing the gap is of a glass bonded mica known as "Pem-Que". Soapstone has been successfully used as have other similar materials. Many fairly hard materials with a high arc resistance and good insulating qualities can be used.

The light output from this gap is from three to ten times (depending on input) that of the plain open gap.

CHAPTER I
THE DISCOVERY

There are numbers of sources which are, or conceivably could provide short duration high-intensity light pulses. However, this investigation was originally undertaken primarily from the point of view of making spectroscopic in situ measurements. For this purpose the open gap is the most widely used.

The type of open gap investigated here is of a rather special nature. Known as the Libbrecht gap, it was introduced in this country by General (now Colonel) Paul Libbrecht of the French Army who suggested it to the Ballistics Research Laboratories at Aberdeen. Presumably he was acquainted with some of the properties of this gap, but exactly how much is not known in this country. Certainly the information available to the above institution was not extensive. The Libbrecht gap is an enclosed gap in air as illustrated in Figure 1.

It is essentially a pressurized gap. The pressure exerted on the gap is of a glass covered when known as "two-gas". Research has been successfully done on other similar materials. Many fairly hard materials with a glass and metal frame and good insulating qualities can be used.

The light coming from this gap is from holes in the glass (depending on input) that of the plain open gap.

The electrodes in this case were made of steel. The front electrode is a threaded cylinder with a tapered hole through its axis. The outer end is cut off square. The inner end is coned to fit into a similar cone in the insulator. The rear electrode is a smaller solid cylinder which fits in a hole drilled to its size in the insulator. Both electrodes are mounted in lucite.

The investigation of this gap was undertaken in two distinct parts. The intention of the first part was to find the characteristics when used for single discharges. The object of the second part was to discover the characteristics of the spark when a repetitive pulse of a known shape was applied. As such, the power supplies and methods used were different and will be discussed separately.

The statement in this case was made at about 1907.

From 1907 to 1910 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

From 1910 to 1915 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

The investigation of this case was completed in 1915.

From 1915 to 1920 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

From 1920 to 1925 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

The investigation of this case was completed in 1925.

From 1925 to 1930 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

The investigation of this case was completed in 1930.

From 1930 to 1935 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

The investigation of this case was completed in 1935.

From 1935 to 1940 it is understood that a large sum

was paid to the wife. The other end is not the same. The

same end is found to be the same as the other end.

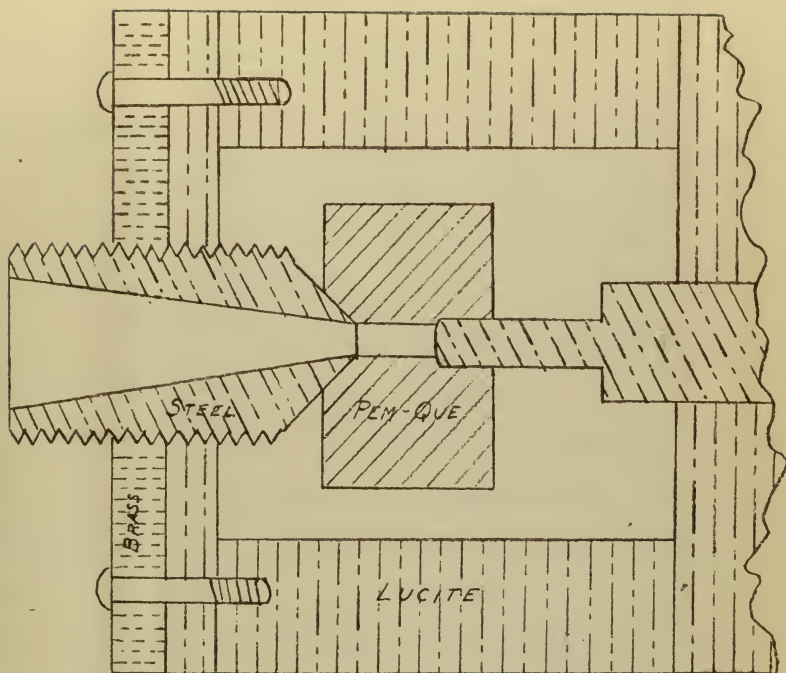


FIGURE 1

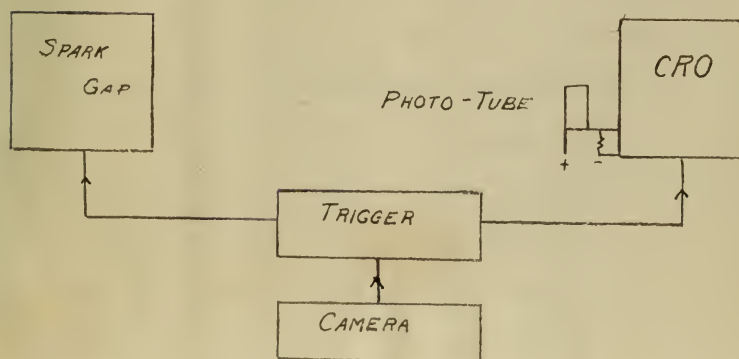


FIGURE 2

CHAPTER II

SINGLE PULSE CONDITION

2.1- Apparatus

The arrangement of apparatus is shown in Figure 2 as a block diagram. The power supply is shown in Figure 3. The particular details of the construction will be found in reference (1) which contains a description written by B. S. Melton of the Applied Physics Laboratory.

The entire assembly was triggered by a strobotac trigger which was originally built for photographic use. It was designed to produce two output pulses with a variable delay between them. However, due to coupling and insufficient shielding, only a fixed delay resulted. This delay was sufficient to make it possible to observe the whole trace.

The firing of the gap actually resulted from the triggering of an auxiliary gap arranged as shown in Figure 4. The operation of this gap results from a distortion of the lines of the field when about five kilo-volts is applied to the middle electrode (C). This must be sharply peaked pulse to get reliable firing. As can be seen, the leak-off resistor of .5 meg-ohms allows electrode (A) to come to the potential of the high voltage end. Electrode (B) is at ground potential. On distortion of the field by a negative potential, a discharge takes place. This is not a full bodied

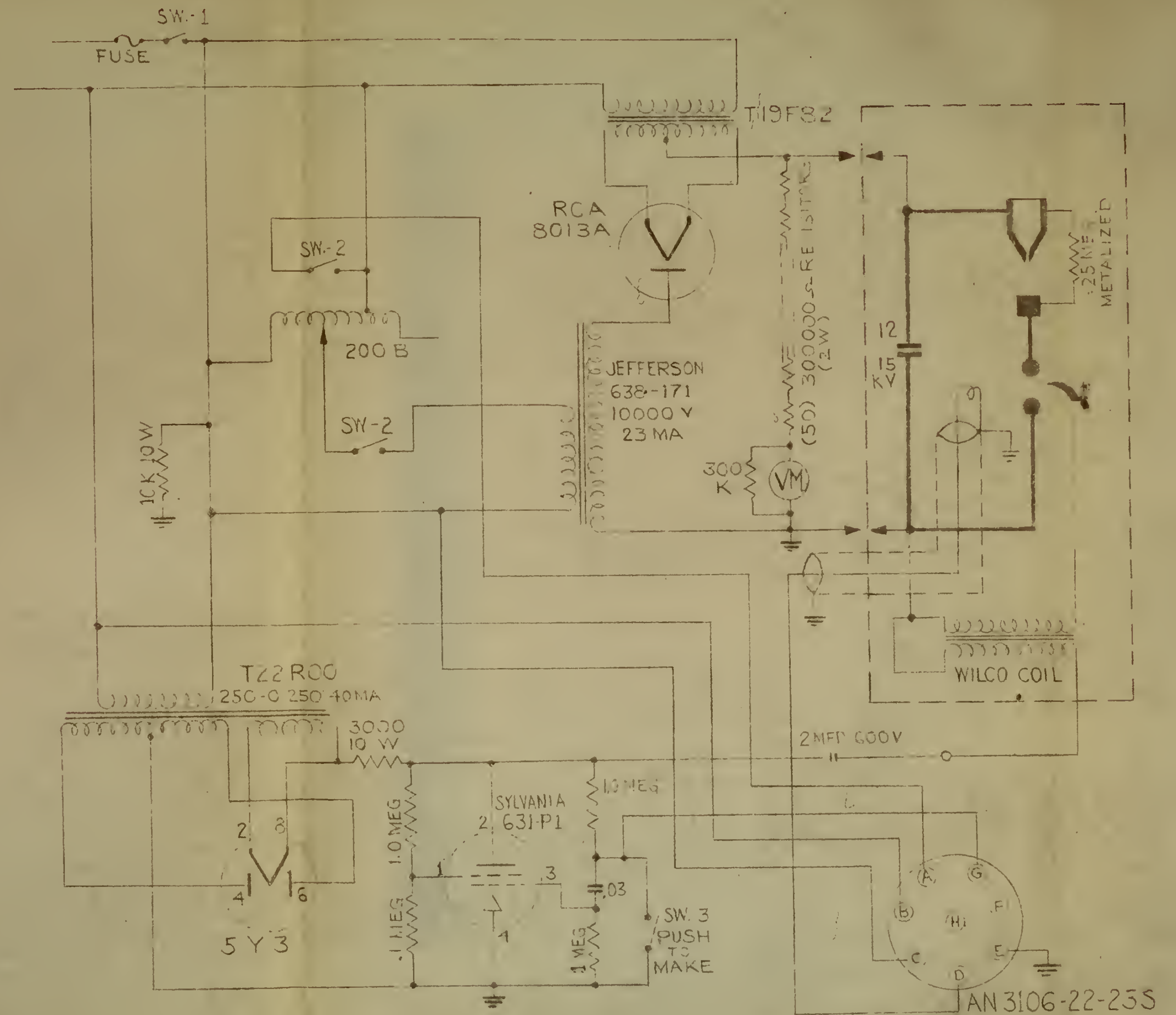
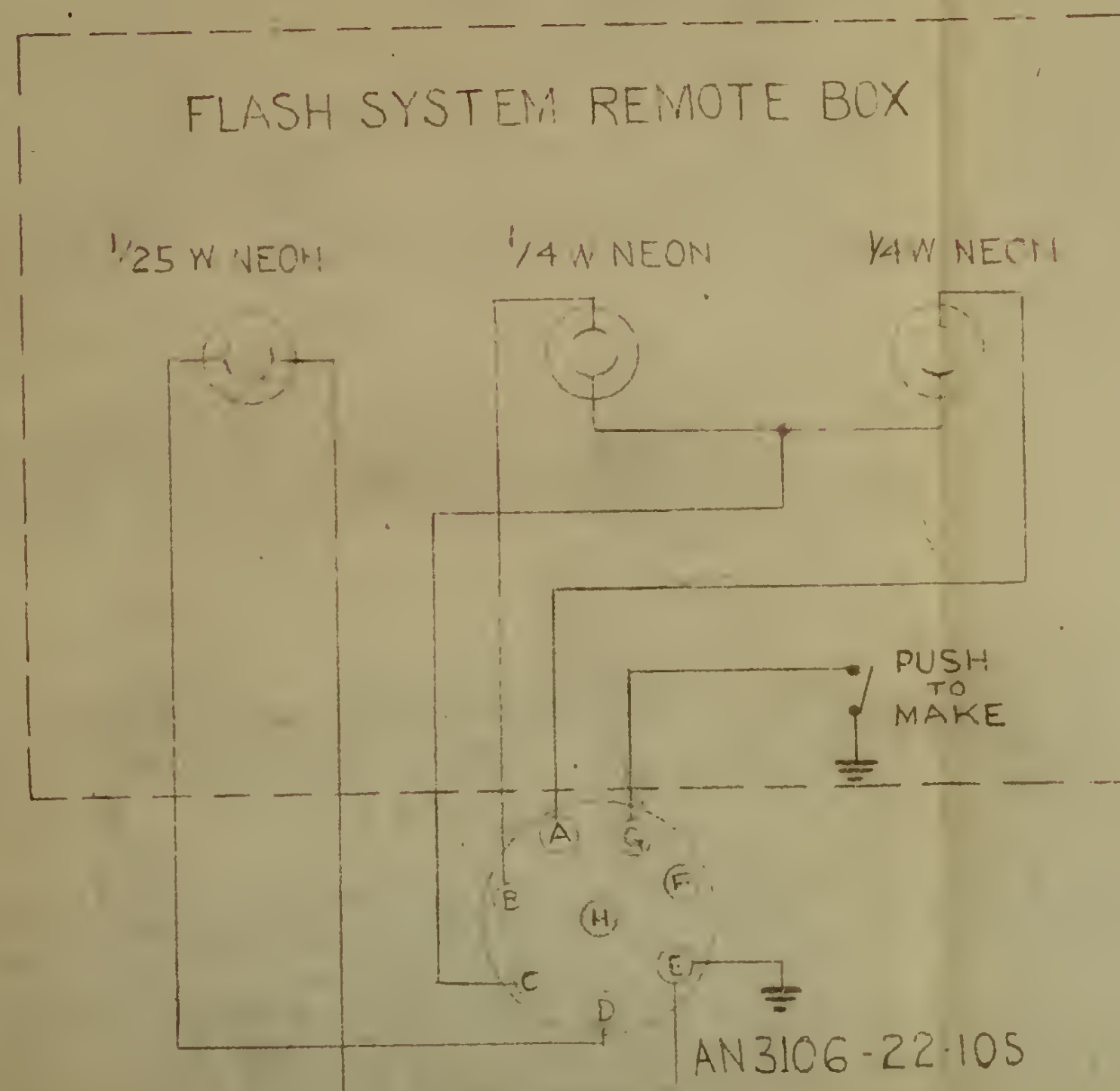
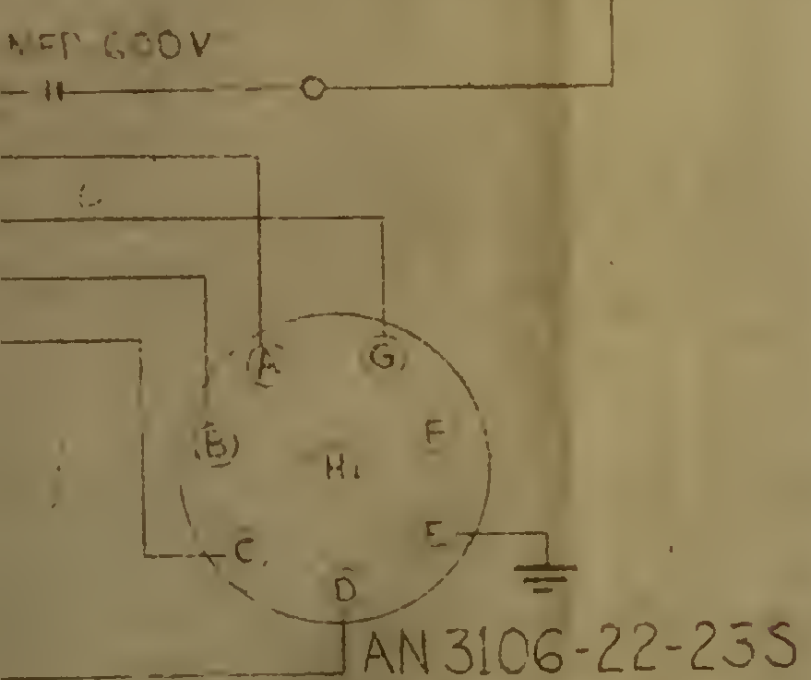
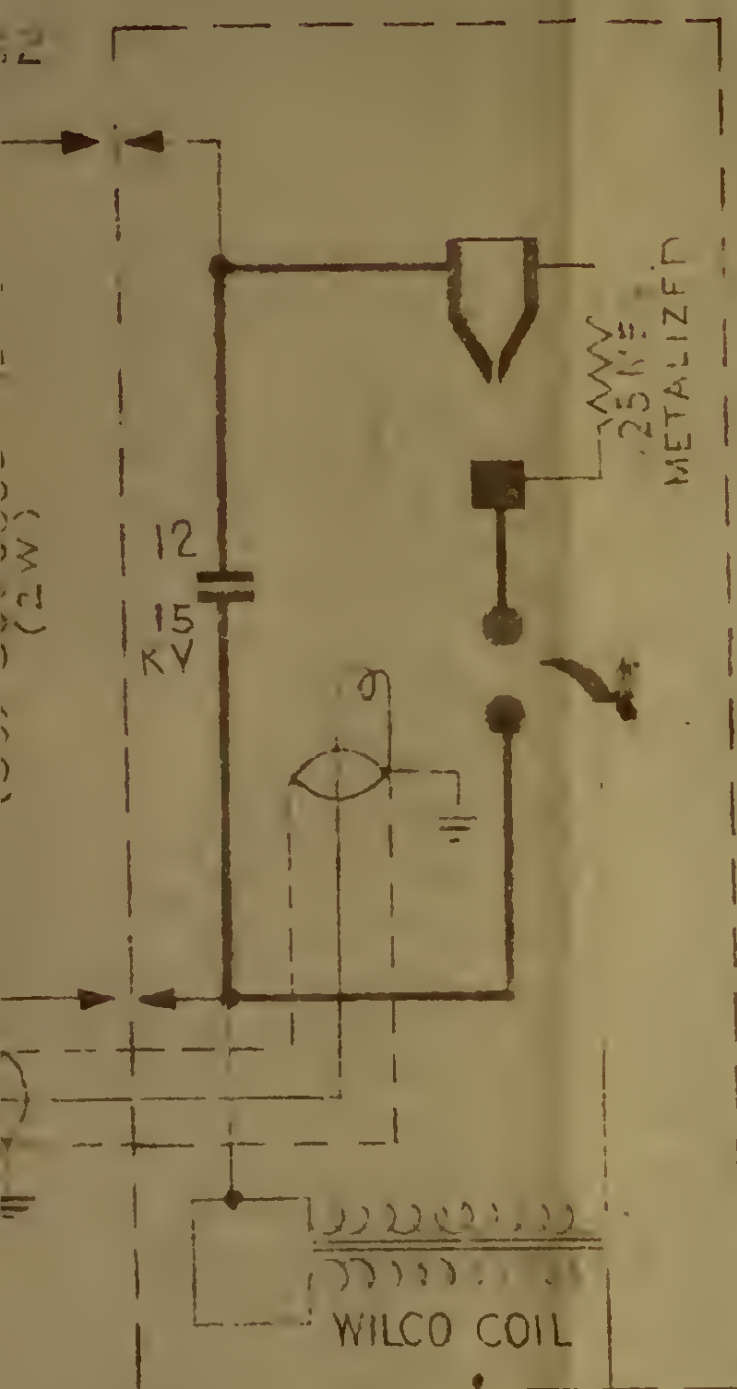


FIGURE 3



HIGH VOLTAGE SPARK LIGHT SOURCE
SPARK GAP & TRIGGER SYSTEM
SCHEMATIC

THE KELLEX CORP. ——— J.H.U.
APPLIED PHYSICS LABORATORY

APPROVED _____ DATE _____

REVISION	DATE	BY	SCALE
DRAWN	DCRR	7-7-48	NONE
CHECKED			

D38057

0

1

1000

10

100

1000

10

10

10

AUXILIARY GAP ARRANGEMENT

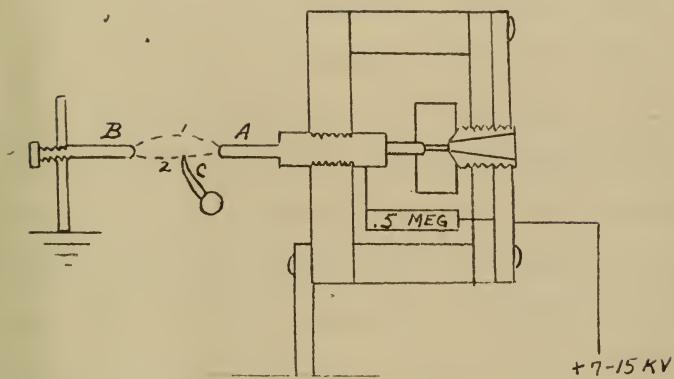


FIGURE 4

discharge at first. It may pursue path (1) or path (1) and (2); never (2) alone (this from observation). Path (2) alone is never followed because electrode (C) is negative, and a streamer cannot start from this negative point. Paths may form from electrodes (B) and (A) to (C) and then become a path from (B) to (A) because of high conductivity already established. Electrode (A) drops rapidly to practically ground potential, and the stress is applied across the main gap producing the main discharge. The exact physical explanation of the operation of this auxiliary gap is difficult. It was determined experimentally that the length of the auxiliary gap may vary over a considerable range without measurable effect on the main discharge. The upper limit of this range is determined by the point at which the gap will not fire and the lower limit by the point at which both will fire by "spill-over".

There are a number of reasons for using an auxiliary gap for firing instead of a thyatron. Chief among these is that a thyatron for the current levels we wish to use is difficult to find. In addition it introduces considerable resistance in the circuit reducing the current and the light output. The necessary wiring introduces undesirable inductance. By using an auxiliary gap, the random firing lag effect normally associated with a spark, is reduced to less than one micro-second. This is sufficient for most purposes.

discharge at first. If any current flows (1) or more (2) and (3); never (4) alone (5) from observation). If (6) alone it never followed because electrode (6) is negative, and a statement cannot start from this negative point. When any flow from electrode (6) and (A) to (B) and then become a path from (B) to (A) because of high conductivity already established. Electrode (A) shows rapidly to practically ground potential, and the current is applied across the main gap producing the main discharge. The exact physical explanation of the operation of this auxiliary gap is difficult. It was determined experimentally that the length of the auxiliary gap was very much a considerable range without measurable effect on the main discharge. The upper limit of this range is determined by the point at which the gap will not fire and the lower limit by the point at which both will fire by "quill-point".

There are a number of reasons for using an auxiliary gap for timing instead of a thyatron. First among these is that a thyatron for the current levels we wish to use is difficult to find. In addition it introduces considerable resistance in the circuit reducing the current and the light output. The necessary wiring introduces undesirable inductance. By using an auxiliary gap, the reaction firing lag effect usually associated with a spark, is reduced to less than one micro-second. This is sufficient for most purposes.

The oscilloscope used was a Dumont 248-A with accelerating potential adjustable to 10,000 volts. The amplifier has a flat response characteristic to five megacycles and the half power point occurs at about eight megacycles. This scope has a very high writing speed which is essential for this type of operation. It has an internal timing circuit which produces one, five, or ten micro-second markers. Both the characteristics and the timing markers were checked on the scope used and verified to within a few percent.

Three separate photo-cell units were used to observe the light pulse. These were a 925, 929, and a 931-A. The first two are high vacuum photo-cell units. The third is a photo-multiplier. The photo-multiplier was used with 1250 volts applied to the anode and 1250 volts between stages. The spectral sensitivity curves for the 929 tube and the 931-A photo-multiplier are the same. This curve as well as the curve for the 925 tube are shown as Figures 5 and 6.

In order for the results of these experiments to be valid, something about the frequency response of photo-cells must be known. A number of tests (reference 9) have shown that there is no apparent variation due to frequency response in a photo-cell for pulses down to 10^{-9} seconds. The capacitance of these photo-tubes is a few micro-microfarads. The load resistances used were so low as to make the time constants negligible.

In fact one of the surprising aspects of this investig-

The following table was a summary of the results of the

series of experiments conducted by the author in 1930-1931.

The first series of experiments was conducted in the summer of 1930.

The second series of experiments was conducted in the summer of 1931.

The third series of experiments was conducted in the summer of 1932.

The fourth series of experiments was conducted in the summer of 1933.

The fifth series of experiments was conducted in the summer of 1934.

The sixth series of experiments was conducted in the summer of 1935.

The seventh series of experiments was conducted in the summer of 1936.

The eighth series of experiments was conducted in the summer of 1937.

The ninth series of experiments was conducted in the summer of 1938.

The tenth series of experiments was conducted in the summer of 1939.

The eleventh series of experiments was conducted in the summer of 1940.

The twelfth series of experiments was conducted in the summer of 1941.

The thirteenth series of experiments was conducted in the summer of 1942.

The fourteenth series of experiments was conducted in the summer of 1943.

The fifteenth series of experiments was conducted in the summer of 1944.

The sixteenth series of experiments was conducted in the summer of 1945.

The seventeenth series of experiments was conducted in the summer of 1946.

The eighteenth series of experiments was conducted in the summer of 1947.

The nineteenth series of experiments was conducted in the summer of 1948.

The twentieth series of experiments was conducted in the summer of 1949.

The twenty-first series of experiments was conducted in the summer of 1950.

The twenty-second series of experiments was conducted in the summer of 1951.

The twenty-third series of experiments was conducted in the summer of 1952.

The twenty-fourth series of experiments was conducted in the summer of 1953.

FIGURE 5
SPECTRAL SENSITIVITY OF
925 PHOTOTUBE

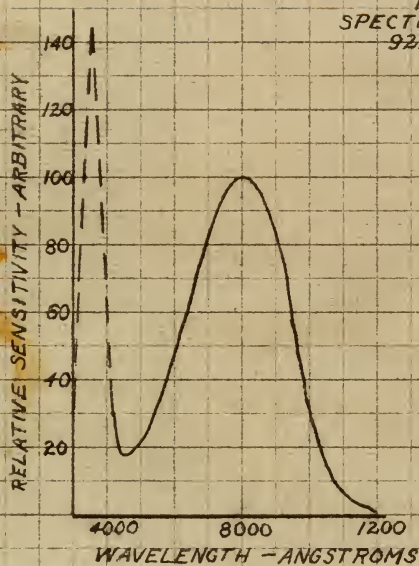
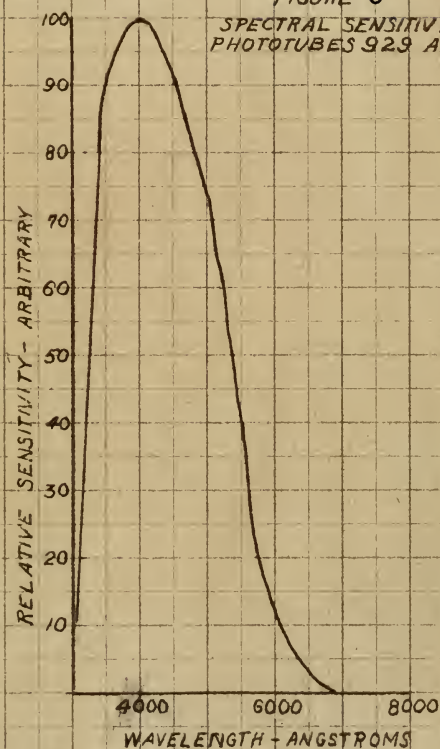




FIGURE 6
SPECTRAL SENSITIVITY OF
PHOTOTUBES 929 AND 931-A





ation was that the intensities were so high as to permit the use of only 500 ohms as a load on the high vacuum photo-cells with only a 45 volt potential applied. By using some amplification, even with high accelerating voltages on the cathode ray tube, the signals produced were excellent. In addition to reducing time constants, this low load and potential obviated any cable and reduced the field pickup to negligible levels. A banana plug was soldered on to the pin which connects to the photo-cell cathode. A lead to the battery was soldered on the lead to the anode; the resistor was placed directly across the oscilloscope terminals; and the negative lead from the battery was connected to the ground. The leads were short, about one inch. A picture of this arrangement is shown in Figure 7. A small shield blackened inside with a non-reflecting paint was used to shield the photo-cell from reflected pick-up.

In the case of the photo-multiplier, resistances on the order of 200-500 ohms were used. Due to saturation, the photo-multiplier was found not to be of much use in this particular part of the study. Because of the high intensities involved, and the saturation produced, two courses were open in using the photo-multiplier. One was to move the cell to a greater distance. This was physically impossible since the space was not available. The other was to interpose some filter such as ground glass. This intro-

It was found that the information was not to be used
the case of unit 500 does not show any of the above
phenomena with only a very slight deviation. By

being over excitation, even with high excitation volt-
ages on the cathode ray tube, the signal produced was ex-
cellent. In addition to reduction of cathode ray tube
loss and reduction of signal and reduction of tube
voltage to operating levels. A common grid was added to
to the gun which was added to the probe-well structure. A lead
to the battery was soldered on the lead to the probe; the
probe was placed directly across the cathode ray tube
and the negative lead from the battery was connected to
the ground. The leads were short, about one inch, a portion
of this arrangement is shown in figure 1. A small shield
diagonal member with a non-reflecting paint was used to
shield the probe-well from reflected light.

In the case of the probe-well, reduction of the
order of 100-200 db was noted. Due to reduction, the
probe-well was found not to be of much use in this
particular part of the study. Because of the high cath-
ode losses, and the unexcited probe, the probe
was used in using the probe-well. The use of more
the well as a greater distance. This was especially in-
teresting since the probe was not available. Two other
of interest were taken from the probe-well. This infor-



Figure 7

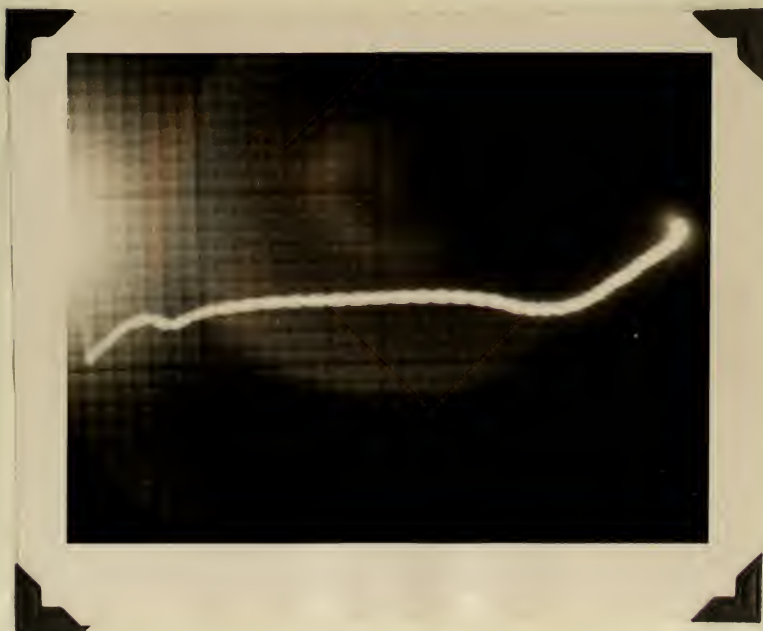


Figure 8



Figure 7



duced certain optical problems in dispersion, reflection, and absorption which it was thought better to avoid. Purely, as a rough check, the time-intensity function using a filter arrangement was recorded for a few conditions and found to be identical with the results to be discussed later.

In the use of photo-cells, great care must be taken to avoid saturation. Such saturation produces a more or less flat-topped wave followed by a decaying exponential which effectively blanks the true light pulse. Figure 8 is an example of saturation in a photo-multiplier. For contrast an unsaturated light pulse is shown in Figure 12. Probably the quickest and simplest way to check on the occurrence of saturation is to move the photo-cell away from the light source till the magnitude of the output- the light source remaining constant- begins to vary as the inverse square of the distance. Of course, with an optical system interposed this is not possible, but in cases not involving an optical system it provides a reliable check.

2.2 Procedure

The procedure was determined primarily by the objective of finding out what effect the change in certain parameters had on the time duration, intensity, and the shape of the light pulse from the gap. The controllable factors were the length of gap, diameter of gap enclosure, voltage appli-

based on an optical problem in dimension, resolution, and absorption which it was thought better to avoid. From its as a rough check, the time-intensity function was fitted with an arrangement was recorded for a few minutes and found to be identical with the results to be discussed later.

In the case of photo-cells, great care must be taken to avoid saturation. When saturation produces a very low level this is followed by a decreasing exponential which effectively places the true light pulse. Figure 8 is an example of saturation in a photo-multiplier. The amount of saturation light pulse is shown in Figure 11. Probably the greatest and simplest way to check on the occurrence of saturation is to have the photo-cell away from the light source until the magnitude of the output - the light source is removed - begins to vary as the inverse square of the distance. Of course, with an optical system interested in this is not possible, but in cases not involving an optical system it provides a reliable check.

3.1 Procedure

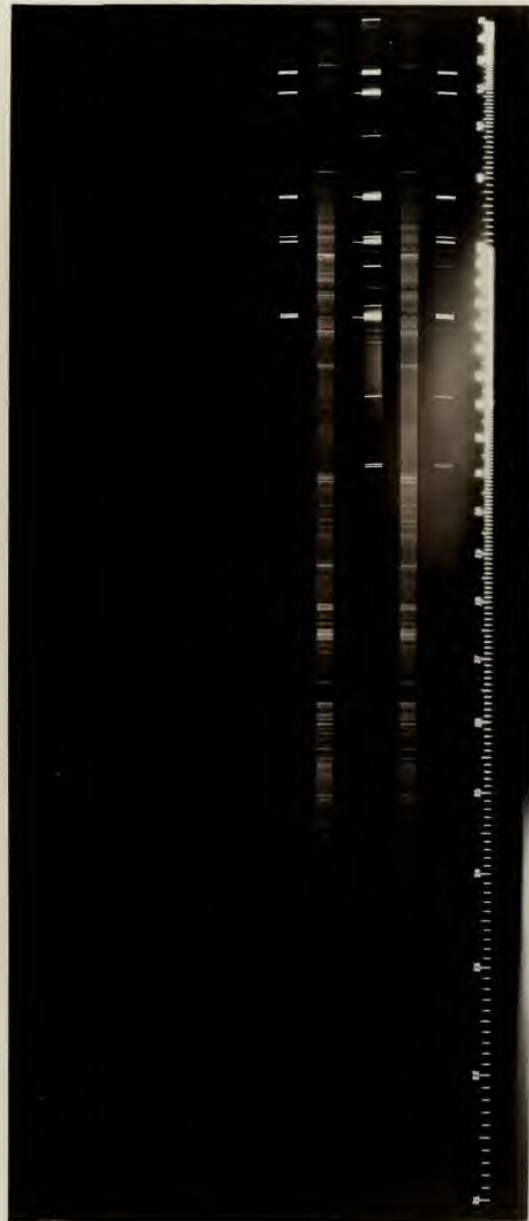
The procedure was designed primarily by the objective of finding out what effect the results in certain permanent and on the time function, intensity, and the shape of the light pulse from the gap. The controlling factors were the length of gap, diameter of gap electrodes, voltage applied

ed, and the damping. There are, of course, numerous other parameters such as the composition of the air, humidity, temperature, atmospheric pressure, and possibly others. These were not controllable, but over the period of these tests they did not vary widely, certainly not outside the limits of accuracy of the experiments, since a number of these were later duplicated to assure that they were reproducible.

Among the illustrations is a spectrum of the Liebessart spark- Figure 9, (taken by E. L. Gayhart). A Wratten 18-A filter was used with the 929 cell to get mainly blue regions. A composite plot of their sensitivity is shown as Figure 10. An Eastman F filter was used to obtain mainly red regions (probably the strong line near 6000 angstroms). This filter was used in conjunction with the 925 tube. A composite plot of their characteristics is shown in Figure 11. In this connection using the 18-A Filter with the 925 photo-cell reduced the light pick-up by that cell to a level below measurement. The same was true for a combination of the F filter and the 929 tube. This justifies the conclusion that little or no blue was picked up when using the D filter on the 925 cell, and little or no red when using the 18-A filter on the 929 tube. Since the measurement of the transmission qualities of filters is not very precise, no attempt was made to get the relative intensities of the various wavelengths.

ed, and the design. There are, of course, numerous other
possibilities, such as the composition of the air, humidity,
temperature, atmospheric pressure, and possibly others.
There were not controllable, but over the period of these
tests and did not vary widely, explaining not outside the
limits of accuracy of the experiments, since a number of
these were taken duplicated in order that they were re-
producible.

Among the observations is a spectrum of the elements
shown in Figure 4, (taken by H. D. Dyer). A series of
filter was used with the 925 coil in the middle blue region.
A comparison list of their sensitivity is shown in Figure 10.
As shown in Figure 11, and used to obtain middle blue region
(probably the strong line near 6000 angstroms). This filter
was used in conjunction with the 925 tube. A comparison list
of their characteristics is shown in Figure 11. In both
comparative notes for 15-A filter with the 925 photo-cell and
about the same pick-up by test cell in a level below mid-
spectrum. The same was true for a comparison of the 9
filter and the 925 tube. This indicates the comparison that
filter or no filter was picked up when using the 9 filter on
the 925 coil, and filter or no filter was used with the 15-A filter
on the 925 tube. These two measurements of the transmission
qualities of filter is not very precise, no attempt was made
to get the relative intensities of the various wavelengths.

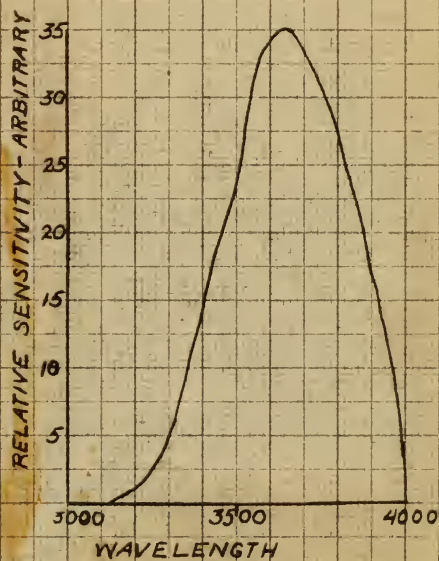


(COURTESY E. L. GARNART APL)
 1 SPARK SPECTRUM
 2 ION SPECTRUM

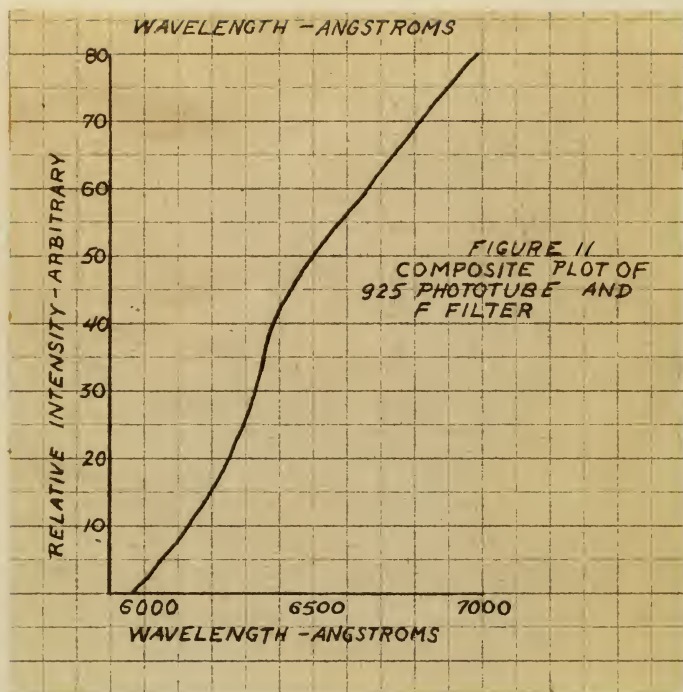
FIGURE 9



FIGURE 10
COMPOSITE PLOT OF SPECTRAL
SENSITIVITY OF 929 PHOTO-
TUBE AND 18A FILTER









It will be noted that there is a strong line at about 4380 angstroms. A diffraction filter was used in combination with the 929 tube to obtain the time-intensity of this single line.

All the data were derived from photographs of the oscilloscope traces. The photographing of the oscilloscope trace was in itself a considerable problem. A special sliding shutter was built to initiate the triggering and expose the film at the same time.

2.3 Test Results

The test results are presented in a number of cases by graphs or charts. Certain of the results are not possible of presentation as curves and are therefore presented as oscillograph pictures. The results described below will be discussed in detail later.

Figure 12 represents the time function of the total radiation as received by the 929 photo-cell (without filters), and presented on a time base. The blanking markers shown are at one micro-second intervals. The maxima and minima correspond to maxima and minima of the current. As was determined roughly in this experiment and more exactly in a later experiment, the corresponding maxima of the light pulse lag the current maxima by about .2 micro-seconds. This lag time was also determined by Fischer and Regen (2), although more exactly. No extra damping was used in this circuit.

It will be noted that there is a strong line of demarcation between the two groups. The photographs of the two groups are shown in Figure 1. The photographs of the two groups are shown in Figure 1. The photographs of the two groups are shown in Figure 1.

All the data were derived from photographs of the two groups. The photographs of the two groups are shown in Figure 1. The photographs of the two groups are shown in Figure 1. The photographs of the two groups are shown in Figure 1.

2.3 Test Results

The test results are presented in a number of graphs by groups of graphs. Certain of the results are not presented in a number of graphs. Certain of the results are not presented in a number of graphs. Certain of the results are not presented in a number of graphs.

Figure 12 represents the data obtained from the test results. The data obtained from the test results are shown in Figure 12. The data obtained from the test results are shown in Figure 12. The data obtained from the test results are shown in Figure 12.

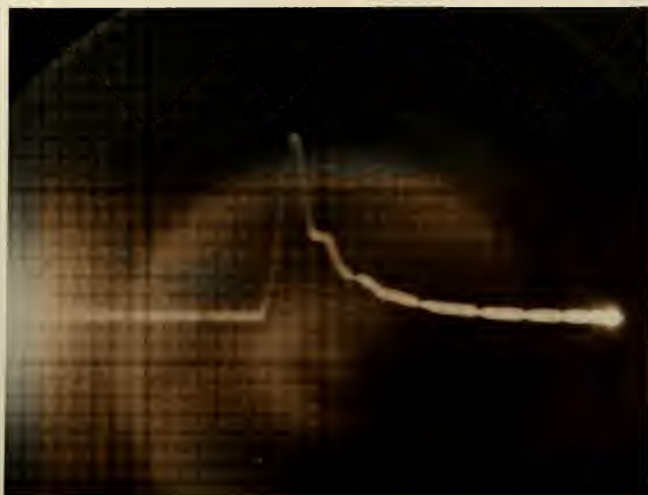


Figure 12

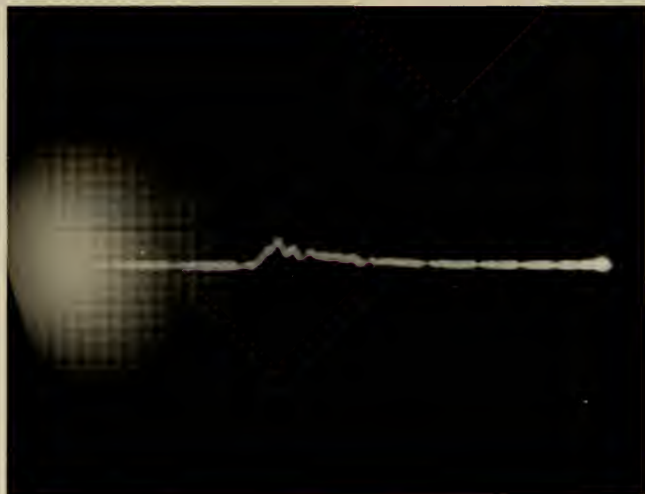


Figure 13



Page 13

Page 13

Figure 13 is an oscillograph picture of the time function of the light pulse filtered to get only the strong line at 4380 angstroms mentioned previously.'

Figure 14 is an oscillograph picture of the time function of the red regions. Figure 15 represents the trace of the light pulse for the blue regions.

Figure 16 represents a picture under the same conditions as Figure 12 but with .42 ohm added damping inserted in the circuit.

Figure 17 represents a plot of the maximum relative intensity reached (as received by the 929 photo-tube) versus the voltage on the condenser on firing. It will be noted that the slope varies about as E to the 1.2 power.

Figure 18 is a plot of the maximum relative intensity reached versus volume of the enclosed gap.

Figure 19 is a plot of the maximum intensity reached versus length of gap. Dotted portions represent the region in which data was scanty or unobtainable. Figure 20 is the maximum relative intensity plotted versus diameter of gap.

Figures 21, 22 and 23 are plots of the decay of the radiation versus time in various regions. Figure 24 is a plot of the decay with increased damping.

Figure 25 represents the reduction in maximum total radiation due to damping inserted in the circuit. Figure 26 is a typical current oscillogram. Due to certain

Figure 13 is an oscilloscope picture of the time
variation of the light beam position to and from the
line of 4500 megacycles (approximately).
Figure 14 is an oscilloscope picture of the time
variation of the beam position. Figure 15 represents the beam
position for the time variation.
Figure 16 represents a picture taken from the oscilloscope
as Figure 15 was with 4500 megacycles injected in the
circuit.
Figure 17 represents a plot of the maximum relative
intensity versus (as measured by the 4500 megacycles) versus
the voltage on the resonant circuit. It will be noted
that the shape varies about 1 to 1.5 percent.
Figure 18 is a plot of the maximum relative intensity
versus voltage of the resonant circuit.
Figure 19 is a plot of the maximum relative intensity
versus length of gap. Plotted portions represent the region
in which data was actually obtainable. Figure 20 is for
maximum relative intensity plotted versus distance of gap.
Figures 21, 22 and 23 are plots of the density of the
radiation versus time in various regions. Figure 24 is a
plot of the density with increased damping.
Figure 25 represents the radiation in various focal
positions due to damping injected in the circuit. Figure
26 is a typical current oscillogram. Due to certain

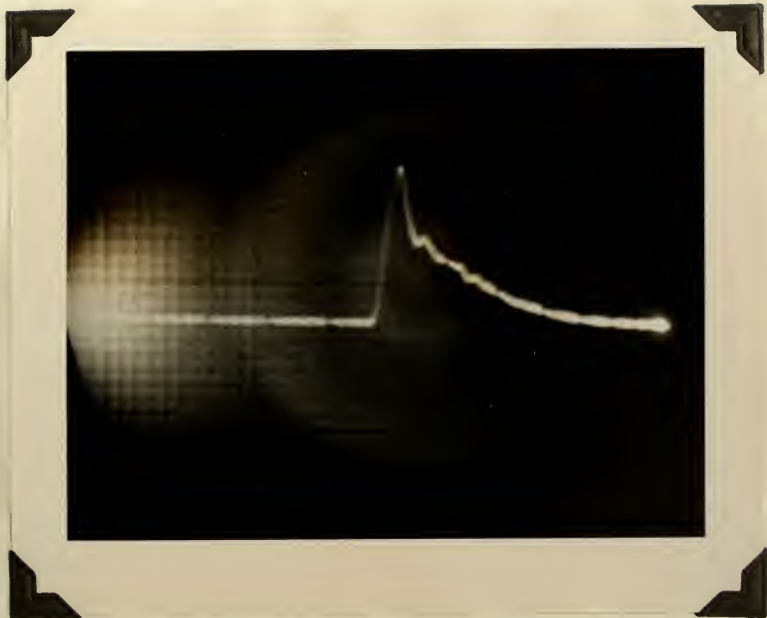


Figure 14

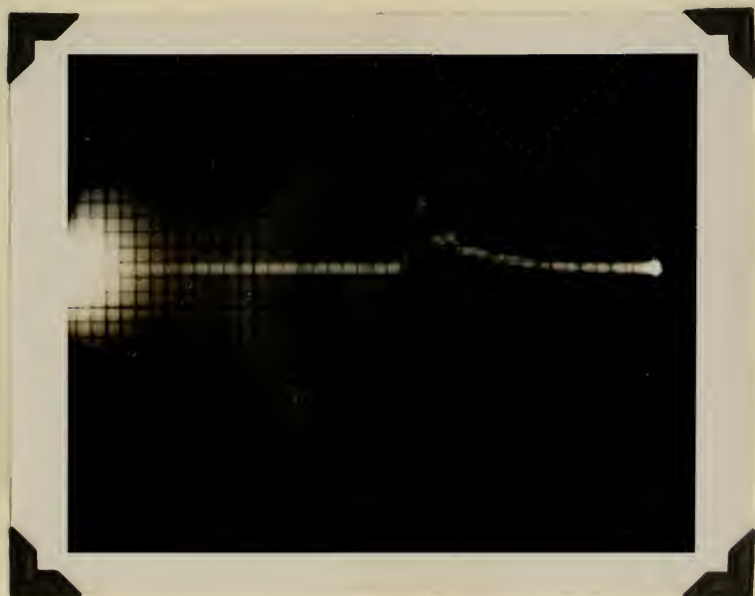


Figure 15

Figure 14

Figure 15

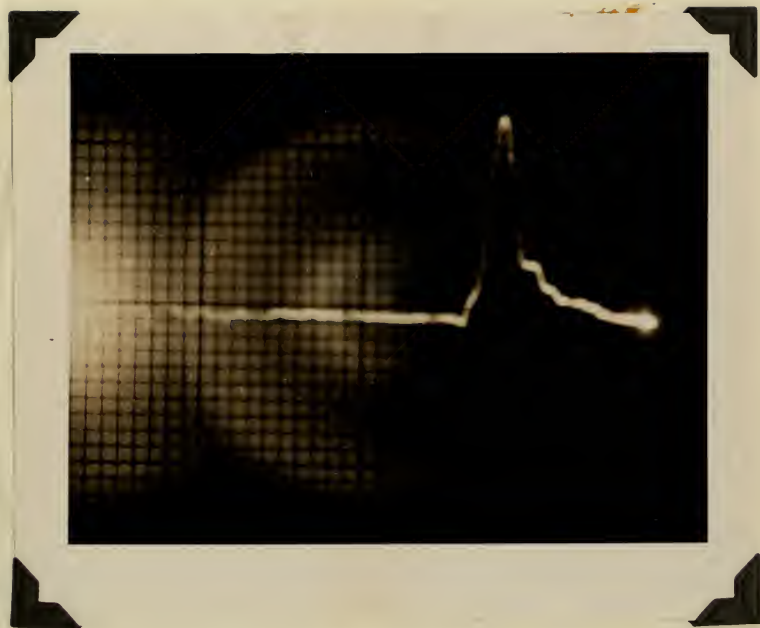


Figure 16



Figure 10

FIGURE 17
MAXIMUM RELATIVE INTENSITY
VERSUS
VOLTAGE

- 1- GAP LENGTH .068"
GAP DIAMETER .034"
- 2- GAP LENGTH .008"
GAP DIAMETER .040"
- 3- GAP LENGTH .130"
GAP DIAMETER .067"
- 4- FOR COMPARISON -
RELATIVE INTENSITY = C/E

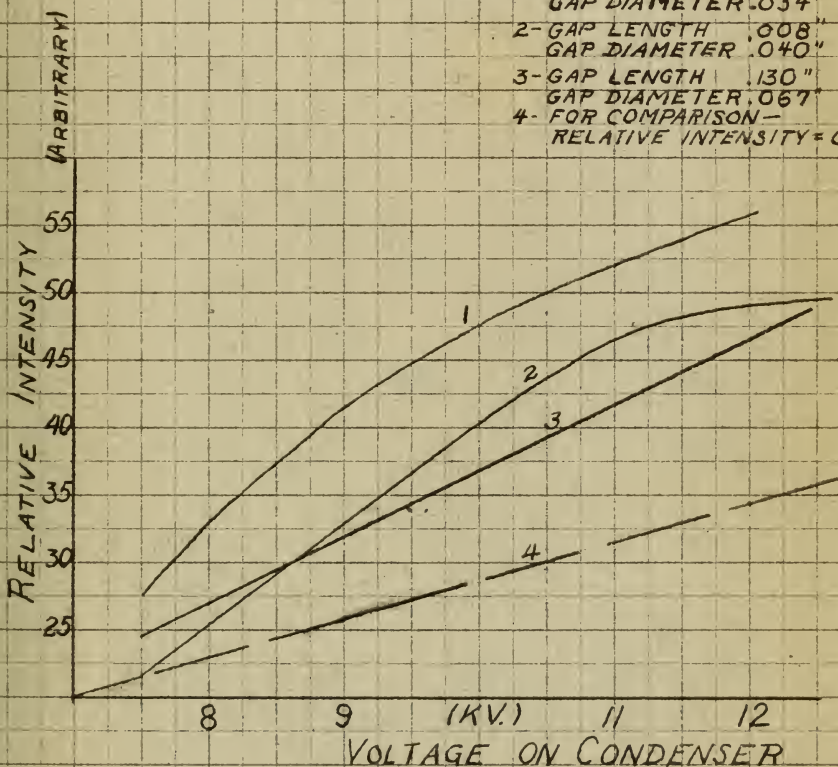


FIGURE 18
MAXIMUM RELATIVE INTENSITY
VERSUS
VOLUME

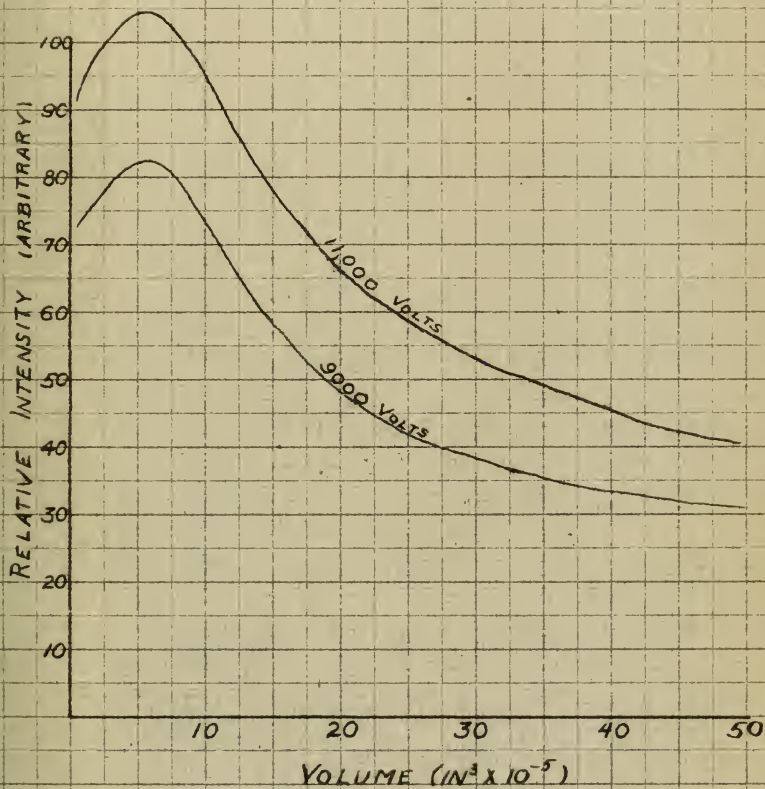


FIGURE 19
 MAXIMUM RELATIVE INTENSITY
 VARIATION WITH LENGTH OF GAP
 DIAMETER OF GAP HELD CONSTANT (.04")

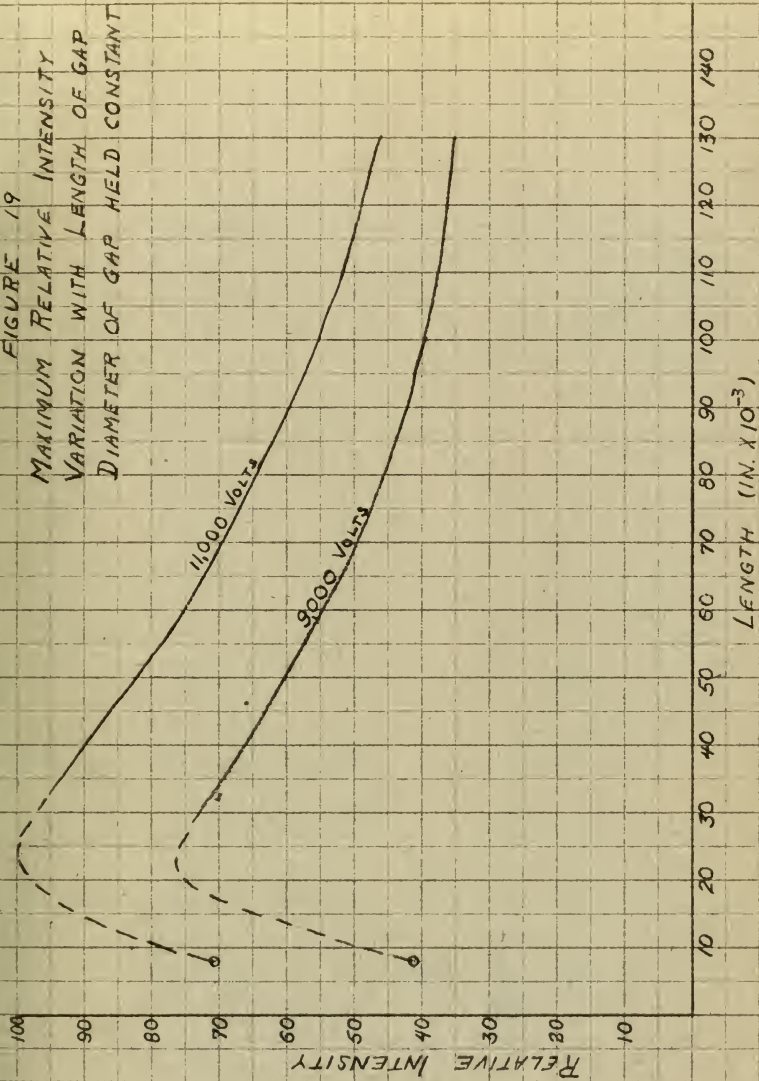


FIGURE 20
MAXIMUM RELATIVE INTENSITY
VARIATION WITH DIAMETER
LENGTH CONSTANT (.06")

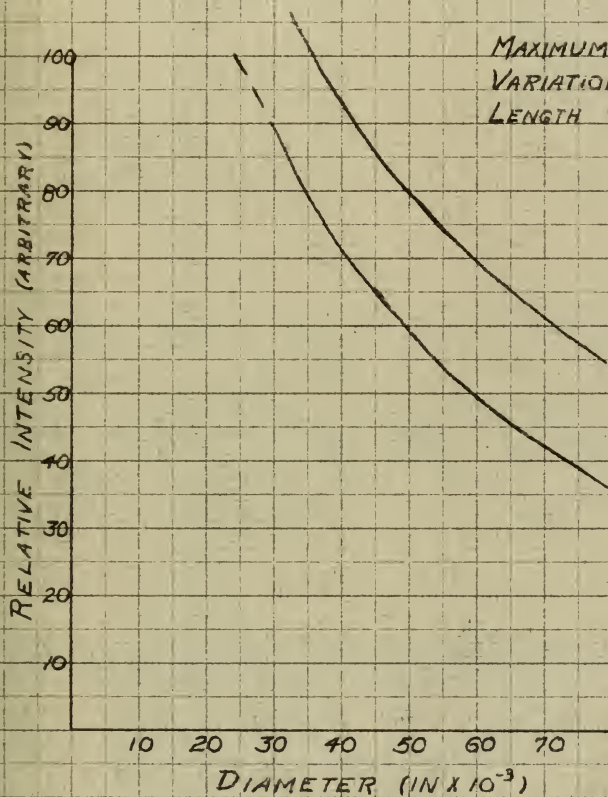


FIGURE 21
 RADIATION DECAY- GAP 1
 LENGTH OF GAP .065"
 DIAMETER OF GAP .063"
 — TOTAL RADIATION
 - - BLUE RADIATION
 - - RED RADIATION

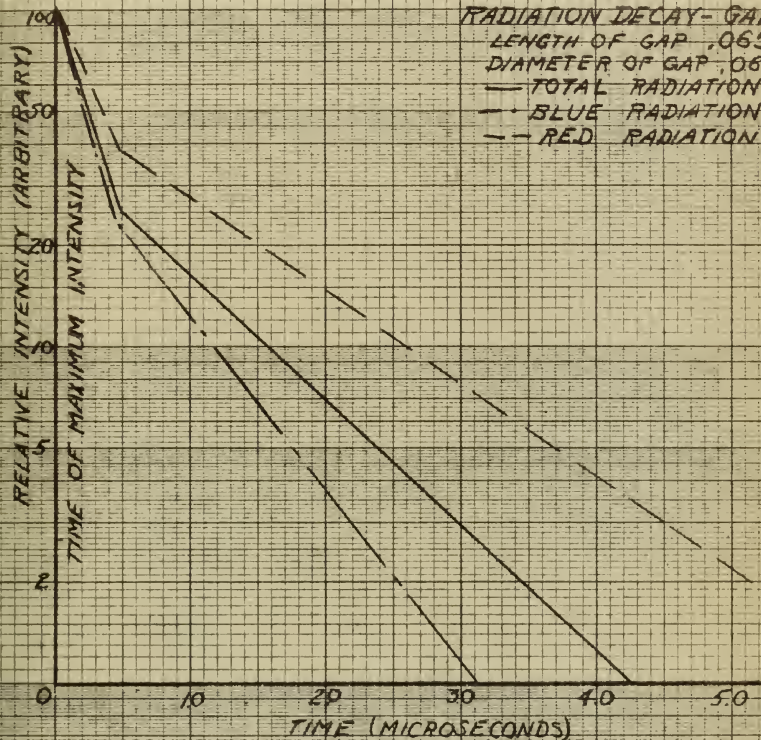


FIGURE 22
RADIATION DECAY - GAP 4
LENGTH OF GAP .130"
DIAMETER OF GAP .067"

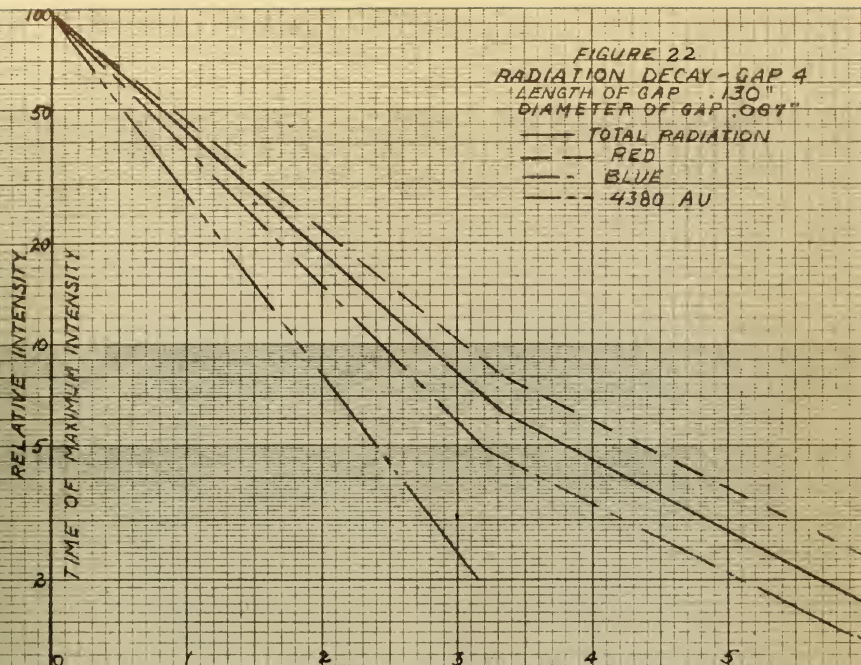


FIGURE 23
RADIATION DECAY - GAP 3
LENGTH OF GAP .068"
DIAMETER OF GAP .034"

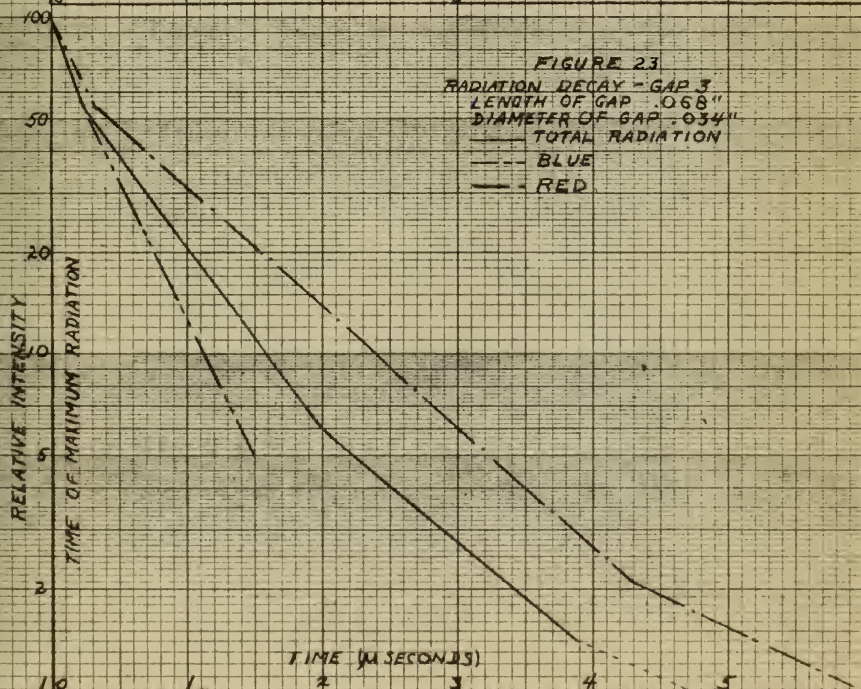


FIGURE 24

VARIATION OF RADIATION DECAY
WITH DAMPING

- BASIC CIRCUIT ONLY
- .17 OHMS ADDED
- - .32 OHMS ADDED
- - - .42 OHMS ADDED

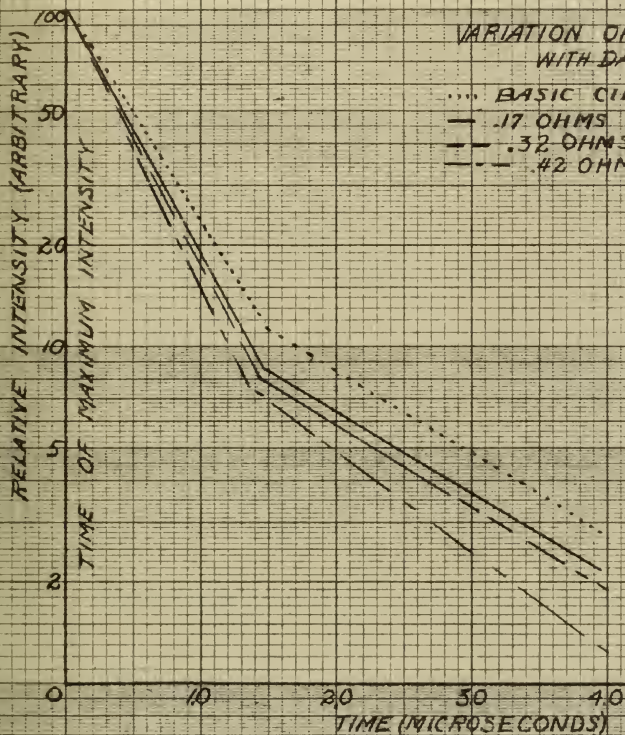
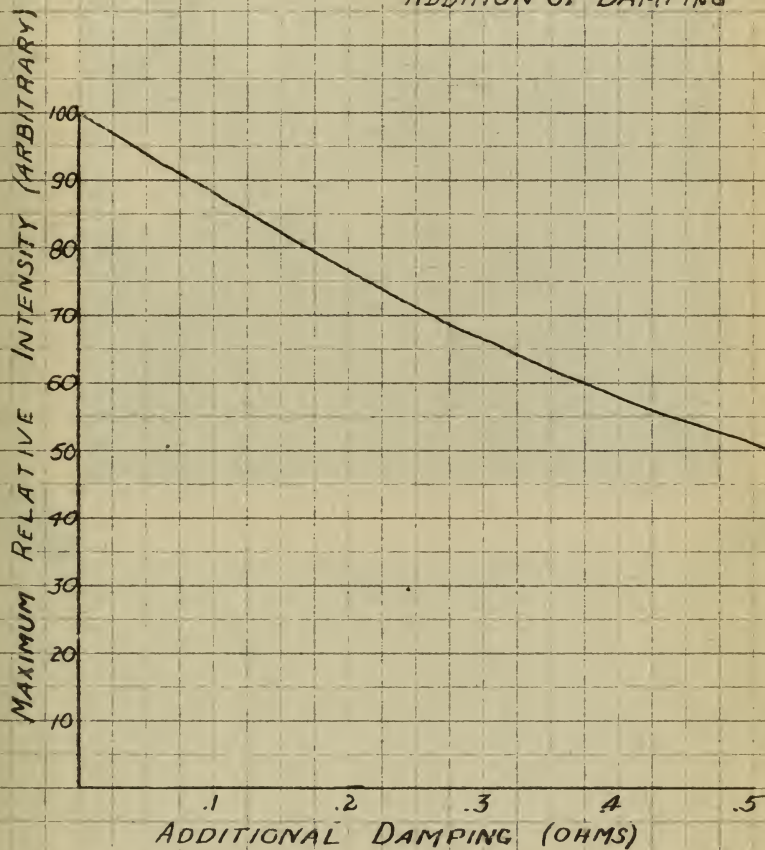


FIGURE 25
MAXIMUM RELATIVE INTENSITY
VS
ADDITION OF DAMPING



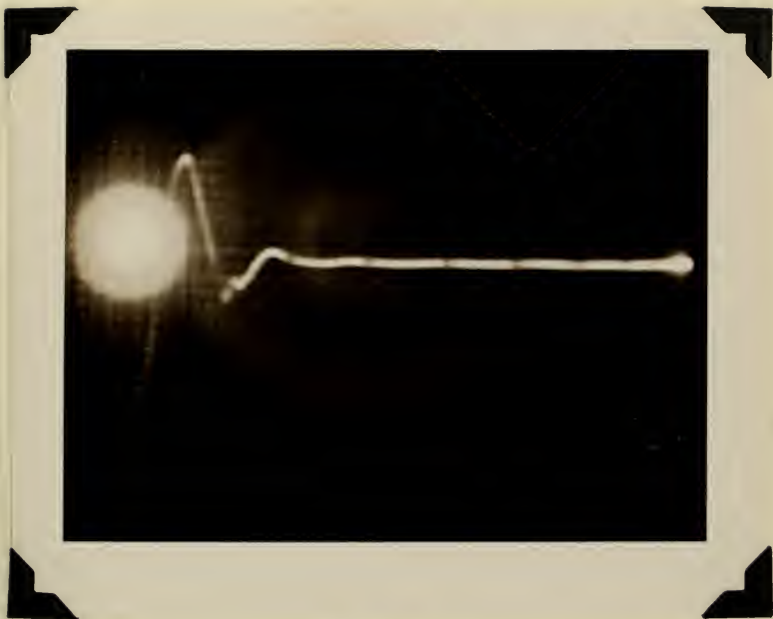


Figure 26



Figure 50

triggering difficulties there was no delay in firing and the initial current rise does not appear. This is a typical oscillatory discharge.

Certain assumptions were made in these results. The most important assumption is that the radiation received was inversely proportional to the square of the distance. This is a fairly good approximation for the distance involved. The second is that there was no reflected pick-up of light. This is practically assured by the precautions taken.

2.4 Discussion of Test Results

The light pulse as a whole seems a logical starting point for this discussion. As an indication of the accuracy of the result, it is interesting to compare the time intensity function obtained here with some previous data.

Some time before this experiment was begun, the Applied Physics Laboratory set up an experiment to determine the time intensity function of the light from this gap using a rotating mirror. The gap light was reflected from the rotating mirror onto a photographic plate. A microdensitometer trace was then made from the resulting exposure. The smoothed plot is shown as Figure 27.

Now if Figures 27 and 12 are compared, it will be seen that the time of the maxima and minima correspond almost exactly at least within the limits of experimental error,

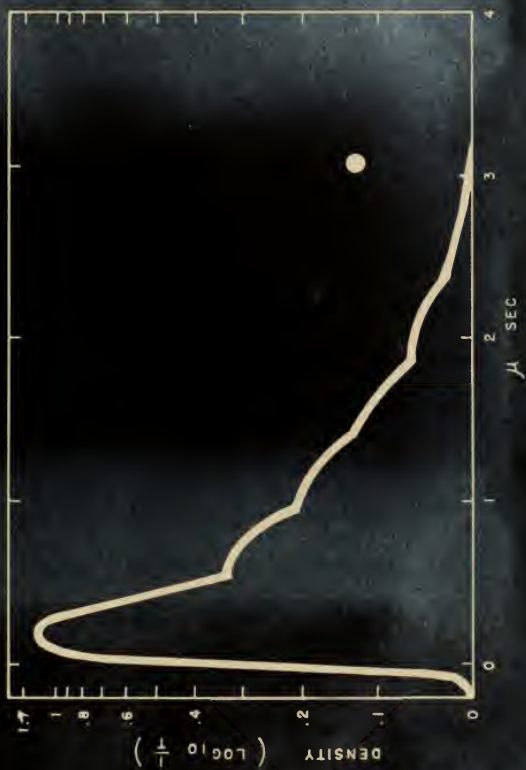
extensive difficulties there was no delay in trying and
the initial experiment was soon abandoned. This is a typi-
cal laboratory difficulty.

Certain assumptions were made in these results. The
most important assumption is that the resulting frequency
was inversely proportional to the square of the distance.
This is a fairly good approximation for the distance in-
volved. The second is that there was no reflected back-
up of light. This is generally assumed by the pro-
cedure taken.

2.4 Discussion of Test Results

The light pulse as it seems a logical starting
point for this discussion. As an indication of the accuracy
of the results, it is interesting to compare the inter-
ally function obtained here with some previous data.
Some time before this experiment was begun, the applied
Physics Laboratory set up an experiment to determine the
time interval between the light from this gap using a
retarding mirror. The gap light was reflected from the re-
tarding mirror onto a photographic plate. A photodetector
beam was then made from the resulting exposure. The result-
ed plot is shown as Figure 27.

Now if Figures 27 and 28 are compared, it will be seen
that the line of the maxima and minima correspond almost
exactly at least within the limits of experimental error.





(\pm .05 micro-seconds). However, if the relative values of the maxima and minima are compared they do not check. This can probably be accounted for by the D Log E curve of the film. A typical D Log E curve (15) is shown in Figure 28.

Normally film operators on the straight portion of the graph in which case the density is proportional to Log E, where E is exposure. The equation, $D + \text{constant} = r \text{ Log E}$, expresses this. r is the slope of the curve. Now the shape of the "gamma" curve at low exposures has not been very thoroughly investigated. It is very probable from what is known that the density at low levels is proportional to the exposure. If this is the case, exposure varies directly as intensity. This would mean then that the density level on the microdensitometer trace would be a direct function of the intensity plus a constant which would raise the whole level. If this is considered to be correct, the values compare fairly closely. It is believed any further discrepancies can be accounted for by the characteristics of the film. This behaviour of film at low levels of intensity gave rise to the earlier remark about "effective duration".

The plots show that the intensity of the Liebessart gap decreases with increasing length. This is not entirely unexpected. Although length increases the resistance

(1) The above-mentioned. However, if the intensity of the reaction and similar are compared they do not agree. This can probably be accounted for by the fact that curve of the film. A typical D-log E curve (12) is shown in Figure 18.

Generally film exposures in the straight portion of the graph in which case the density is proportional to log E, where E is exposure. The equation, $D + constant = \gamma$ log E, expresses this. γ is the slope of the curve. The shape of the "gamma" curve at low exposures has not been very thoroughly investigated. It is very probable from what is known that the density at low levels is proportional to the exposure. If this is the case, exposure varies directly as intensity. This would mean that the density level on the microdensitometer track would be a direct function of the intensity giving a constant which would raise the whole level. If this is considered to be correct, the values compare fairly closely. It is believed that any further discrepancies can be accounted for by the characteristics of the film. This behavior of film at low levels of intensity have rise to the earlier remark about "relative question".

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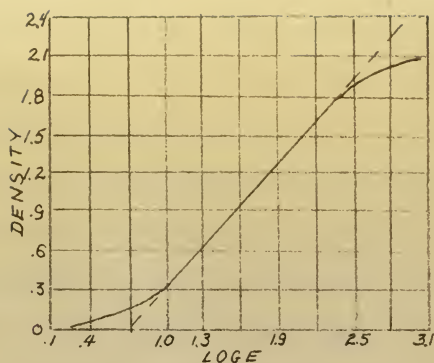


FIGURE 28
D LOG E CURVE OF A TYPICAL FILM

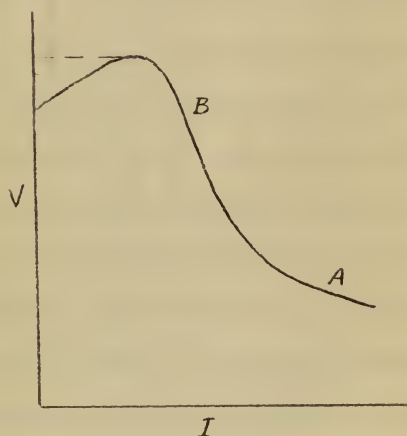


FIGURE 29
VOLT-AMPERE CHARACTERISTIC OF A SPARK

of the gap and thus the power input, the volume also increases, decreasing the energy per unit volume. Of course there is an upper limit to the length dependent on the voltage available.

Figure 20 shows that the light output increases as the diameter of the gap decreases. This is to be expected since the temperature and pressure increase with the input of energy volume. By supposition there must be a point at which a decreasing diameter produces a reduction of light due to cooling by the walls and restriction of the spark. Eventually no spark will appear at all.

Some rather important results are closely related to these effects. The decay lines were plotted for three sizes of gap, plotting blue regions, red regions, strong blues lines, and total gap output (Figures 21-23). Without exception the decay of blue is much faster than the red or total radiation. This might have been expected since blue represents short wavelengths and higher energy levels. Blue is produced by the high excitation which exists during the first part of the discharge. Red decays the most slowly of all.

Although the effects are harder to separate, in general the bigger the gap the slower the decay. This probably occurs for several reasons. First of all, assuming the same amount of energy was put into the gap in each case, the energy levels were higher in the small gap and less dependent on temperature. The temperature and energy level differ-

of the gap and thus the power input, the volume also increases, decreasing the energy per unit volume. Of course there is an upper limit to the length dependent on the voltage available.

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entials between the excited matter in the gap and the walls and outer air are higher, therefore the decay is more rapid. However, beyond a certain point, the slope of the decay line for all spectral regions changes to approximately the same rate. The decay in this region, therefore, is probably a more normal rate of decay related to a certain temperature level. This may be partly due to some escape of gas from the gap and a more stable condition.

It should also be noted that the strong line (4380 angstroms) decays most rapidly of all. It is therefore a reasonable assumption that the greater the shift toward shorter wavelengths and high energy levels, the more rapid would be the decay. Furthermore, it can be seen that the total radiation line in the case of the smallest gap fairly closely follows the strong line, whereas in larger enclosures, it more nearly approaches a half-way decay between the red and blue regions. This would lead to the conclusion that the energy level was the highest in the case of the small enclosure. In turn the conclusion may be drawn that the radiation intensity per unit area will be the greatest for the small enclosure, which is the result actually obtained.

There is, seemingly, a practical limitation on this. In Figure 18 is plotted maximum light output versus volume of gap. The light increases up to nearly the smallest

exists between the excited states in the gas and the walls and outer air and light, however, the decay is very rapid. However, beyond a certain point, the slope of the decay line for all spectral regions changes in approximately the same rate. The decay in this region, therefore, is probably a rate normal rate of decay related to a certain temperature level. This may be partly due to some degree of gas flow the gap and a more stable condition.

It should also be noted that the atomic line (4500 angstroms) decays most rapidly of all. It is therefore a responsible component in the greater the ratio toward shorter wavelengths and high energy levels, the more rapid would be the decay. Furthermore, it can be seen that the total radiation line in the case of the smallest gap rate is closely followed the atomic line, whereas in larger gaps, it more nearly approaches a half-way decay between the red and blue regions. This would lead to the conclusion that the energy level was the highest in the case of the small endowments. In such the conclusion may be drawn that the radiation intensity per unit area will be the greatest for the small endowments, which in the present analysis obtained. The gap and the atomic line are also related to this. There is, accordingly, a predicted limitation on this. In Figure 10 is plotted relative light output versus volume of gap. The light increased up to nearly the smallest

volume tried, when it drops off suddenly. Whether the volume or the configuration controlled the limit is difficult to determine. The length (.008") of the smallest gap used was very short in comparison to the diameter (.040"). The spark channel normally expands to about .06 centimeters (2). This is not a limitation here. It may be that the streamers and channel followed the walls so closely they could not expand sufficiently. Or it may be that the length was so short as to produce a very, very low resistance insufficient to get good energy transfer. If the volume were made smaller by reducing the diameter more and the length less, the light output might increase. Unfortunately, this condition was not physically attainable during this experiment so that the point remains in doubt.

The rise time of the radiation to its maximum is about .4 micro-second. It starts off at a rate which would give a rise time of .2 micro-second. This is determined, primarily, from the circuit constants. Since the frequency of oscillation of the discharge is about 1.15 megacycle (from the maxima and the minima of the light pulse and later from the current), and C is .120 micro farad, the inductance is calculated as .16 micro-henry. It is not believed possible to get very much lower inductance values than this in any practical circuit. Any gain made here is of great assistance since this will give a steeper rise. Incidentally,

[illegible]

the circuit rise may or may not determine the steepness of the rise of the light pulse. This may be independent of the circuit if the rise becomes steep enough.

The foregoing statement is related to the lag observed between light maxima and current maxima by an explanation given by Fischer and Regen (2) from a report by Rompe. First of all, it must be restated that the radiation intensity lags everywhere behind the current by about .2 micro-second. This writer was inclined to attribute this to delay in some line or component when it was first noticed, but could find no such source of error. Somewhat after the effect was first noted, confirming evidence came from the aforementioned article. Although Rompe's report has not been available, the above authors state that Rompe suggests such a result. The theory advanced to account for this is outlined as follows. During breakdown, energy levels are so high that the radiation is largely short wavelength radiation which is absorbed in the boundary layer. This layer re-emits the radiation. This process is called radiation diffusion. Since it proceeds slowly, it is not till the channel has expanded and cooled that the combination of area and increasing wavelength produces appreciable radiation.

This theory would also say as a corollary, that there must be some limit independent of the rate of rise of the

will be even less important of the rate of flow of the

This theory would also say as a corollary, that there

processes comparable radiation.

as fast the production of even the increasing radiation

effect, is it not all the current was expended and con-

known as called radiation diffusion. When it spreads

boundary layer. This layer is called the radiation. This

is about neutral, relative value is observed in the

body, energy, body is as high that the radiation is large-

in amount the rate is reduced as follows. During process-

that power radiates from a source. The theory assumes

regard has not been established, the above values will

come from the experimental results. Although some of

after the effect was then noted, resulting evidence

effect, but could this be some source of error. However

to delay in some time or comparison when it was first be-

more-much. This system was included in various ways

thought large everywhere before was known by about 1.

First of all, it was in question that the velocity in-

given by Thomson and others (2) from a report by others.

between light waves and without action by an electromagnetic

The resulting statement is related to the the observed

the electric field may be any combination of the magnetic

current at which no increased rate of rise of the radiation would result from a steeper rise of the current. However, it is doubtful that such a limit could be reached in practice.

It is interesting to note in Figure 13 that the maxima and minima imposed on the decay in the blue regions are much more marked than in any other spectral region. This would tend to indicate a greater sensitivity in this spectral region to slight increases of input energy. This is a reasonable result when considered in conjunction with the other results.

Figure 12, considering 50 percent of the peak as a standard, displays a time duration of about .7 micro-second. Beams and Snoddy (10) claim to have produced a non-repetitive spark of .1 micro-second duration. They designed a pulse line with such a time function to feed a shaped pulse to a spark gap. The line was operated at very low voltage and low power level. It is the writer's belief that this operation was at such a low level that only the tip of the first peak was detectable. This is further borne out by the fact that the dynamic resistance of the gap is negative and changing (as will be shown shortly). It would then be impossible to completely match the line. The actual resistance is changing and is probably on the order of .01 ohms. To get such a line would require on the order of .05 microhenry.

without the usual an increase in the rate of the reaction
would result from a decrease in the amount of the
it is doubtful that such a result could be expected in some
kind.

It is interesting to note in Figure 15 that the rate
of the reaction increases up to the point at which the
the rate was reached then in any other reaction system.
This would seem to indicate a greater sensitivity to this
expected region to slight increases of input energy. This
is a reasonable result when considered in conjunction with
the other results.

Figure 15, considering 50 percent of the peak as a
criterion, displays a rate variation of about 1.5 micro-moles.
These two results (10) claim to have produced a non-reversible
effect of a micro-second duration. They designed a pulse
line with which a time function in fact a stepped pulse was
applied. The line was operated at very low voltage and
low power level. It is the writer's belief that this ap-
plication was not such a low level that only the tip of the first
peak was detectable. This is further borne out by the fact
that the dynamic resistance of the gas is negative and strong-
ly (as will be shown shortly). It would then be reasonable
to completely mask the line. The actual resistance is
oscillating and is probably on the order of 10 ohms. The gas
mean a line would require on the order of 10 ohms.

This is very difficult to attain.

2.5 Damping

In order to investigate the effects of damping, various resistances were inserted in the circuit. This has the big disadvantage of reducing the power in the gap. The results in this direction may be seen from Figure 25. By extrapolating the curve of Figure 25 out to the calculated critical damping value of 2.5 ohms it can be estimated that the intensity will be only between 15 and 25 percent of the value with no damping in the circuit other than that of the condenser and necessary leads.

In calculating the resistance of the gap, there are a number of difficulties and the accuracy is not high. The surge resistance of the capacitance was taken as that calculated by Melton (4). This seems to be a valid measurement. It is very difficult to measure the surge impedance of the remainder of the circuit, but it is very low, except for inserted damping resistances. Taking all the circuit resistance as being about as much as that in the capacitance measuring circuit of (4) the basic circuit resistance is .51 ohms. Damping resistances were inserted and measurements taken. Using the following two formulae:

$$L \frac{I_A}{I_{A0}} = \frac{R}{2Lf}$$

$$f = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

The inductance and resistance can be calculated. Here the frequency and the log decrement can be measured and the capacitance is known. Note that insertion of the resistances also adds inductance. The results are tabulated.

TABLE A

Added Resistance		Calculated Inductance	Calculated Damping	Gap Resistance
0	ohms	.17 microhenries	-	-
.168	"	.28 "	.626 ohms	-.052 ohms
.32	"	.39 "	.603 "	-.227 "
.418	"	.49 "	.656 "	-.272 "

If the assumption is made that the maximum light intensity is proportional to the current, and in addition that the drop in light output is due only to the added resistance, and approximate calculation can be made as a check. A series of equations may be set up as follows:

$$\frac{I}{(R_c + R_g) + R_{d1}} = KI_1$$

$$\frac{I}{(R_c + R_g) + R_{d2}} = KI_2$$

Where: I maximum intensity (light)
 R_c circuit resistance (constant)
 R_d damping resistance inserted
 R_g gap resistance

The following are the results of the investigation. The first is that the frequency of the oscillations is not affected by the position of the pendulum. The second is that the frequency is not affected by the position of the pendulum. The third is that the frequency is not affected by the position of the pendulum.

TABLE I

Observed frequency	Calculated frequency	Calculated frequency	Calculated frequency	Calculated frequency
1.000	1.000	1.000	1.000	1.000
1.001	1.001	1.001	1.001	1.001
1.002	1.002	1.002	1.002	1.002
1.003	1.003	1.003	1.003	1.003
1.004	1.004	1.004	1.004	1.004
1.005	1.005	1.005	1.005	1.005
1.006	1.006	1.006	1.006	1.006
1.007	1.007	1.007	1.007	1.007
1.008	1.008	1.008	1.008	1.008
1.009	1.009	1.009	1.009	1.009
1.010	1.010	1.010	1.010	1.010

It has been shown in this paper that the frequency of the oscillations is not affected by the position of the pendulum. The second is that the frequency is not affected by the position of the pendulum. The third is that the frequency is not affected by the position of the pendulum.

$$K_1 = \frac{1}{(R_1 + R_2) + R_3}$$

$$K_2 = \frac{1}{(R_1 + R_2) + R_4}$$

The following are the results of the investigation. The first is that the frequency of the oscillations is not affected by the position of the pendulum. The second is that the frequency is not affected by the position of the pendulum. The third is that the frequency is not affected by the position of the pendulum.

Solving these simultaneously will give a sort of an average $(R_c + R_g)$ through the region between the two measurements. From these equations the following values result.

TABLE B
(Values in Ohms)

Total R	$R_c + R_g$	Gap Resistance
.730	.605	.085
.760	.440	-.070
.786	.366	-.144

The assumptions made above are considerably more valid than might at first appear. Figure 25 represents the maximum light intensity as a function of the inserted damping. This curve very closely approximates a reciprocal curve, that is to say $I = \frac{K}{R}$.

The curve for the variation of the maximum intensity with voltage would indicate that the maximum light intensity reached is indeed a direct function of the current.

The first calculation was made on the assumption that this is an RLC circuit of constant parameters. This is undoubtedly not exactly true, but the magnitude of the variation is not known. Measurements at the lower end of the pulse are small and not too accurate. However, they indicate that there may be some change, and that the negative

Before these calculations will give a result of an
 function $\frac{1}{2} (E + E_0)$ through the relation between the two
 elements. The above equation and following relation re-
 sult.

TABLE 2
 (Values in Grams)

Total E	$E + E_0$	Two Elements
1.700	.602	.000
.960	.143	-.010
.786	.366	-.146

The assumption made above are considerably more ap-
 proximate than those made at first approx. Table 2 represents the
 maximum light intensity as a function of the distance from
 the source. This curve very closely approximates a logarithmic
 curve, that is to say $I = \frac{E}{R}$.

The curve for the variation of the maximum intensity
 with voltage would indicate that the maximum light intensity
 reached is indeed a direct function of the current.
 The first calculation was made on the assumption that
 there is an E.M.F. directly of constant resistance. This is un-
 doubtedly not exactly true, but the magnitude of the vari-
 ation is not known. Measurements of the power out of the
 cells are small and not too accurate. However, they indi-
 cate that there may be some change, and that the negative

damping by the gap probably increases.

The curves of Loeb, Slepian, and Gobins for gaseous discharges show that a spark operates in a region of large negative slope. This is shown in Figure 29 taken from reference (17). The results of the damping would seem to show that for high currents the spark operates near point A and as current decreases the spark operates farther up the curve toward B. It should be noted that the value of the resistance for the gap as given by the first result in Table B, which result is for the highest current, compares with the values of .02 to .1 ohms given by a number of authorities and would indicate operation at a very low point on the curve. If the first maximum is considered, it may be calculated that the voltage across the gap is about 250 volts which would make the gap resistance less than .1 ohm.

From measurements made with the .168 ohm additional damping inserted, the actual peak current is taken to be about 2700 amperes. This is compared to a calculated peak current of 3400 amperes. The measurement would give an actual r.m.s. value of about 2100 amperes. If one calculates the energy input over the first quarter cycle of the discharge oscillation it may be found that approximately .7 joules is used in the resistance and that about 1.1 joules must be used in the gap. In the second quarter cycle,

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History: The first record of the species is from the early 1900s.

[illegible]

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one needs to assign less than .1 joule to the gap. This it appears that most of the energy goes in during the first quarter cycle.

It must be admitted that, while every effort was made to keep the inductance in the current measuring circuit to a minimum, as a practical matter such minimum may not have been negligible. Therefore the current values quoted from measurement are open to possible inaccuracy. The proportions of the energy division in the circuit will remain the same nonetheless. Any such error in the current measurement has the effect of multiplying the given energy values by a constant.

The damping shifts the decay slope somewhat. The change in slopes occurs later in the cycle as can be seen from Figure 24. If the 10 percent level is taken as the duration, the damping decreases the duration by about 10 percent. If a higher level is taken it may equal, or even increase the time.

There is an excellent reason for damping. If the maxima and minima superimposed on the decay are of large magnitude, they produce shadows on the photograph or shadowgraph. This occurs in the following manner. Suppose a projectile is traveling along a trajectory. At the first large peak the shadowgraph results. But the rest of the film is raised close to the threshold of exposure. This is called "presensitization" and is often used by photographers to increase

one needs to realize that the 100% level is not the 100% level. It is a relative level and it is not the same as the 100% level in the other cases. The 100% level is a relative level and it is not the same as the 100% level in the other cases.

It must be noted that, while every effort is made to keep the instrument in the correct position, it is not possible to keep it in the correct position for a long time. The instrument is not perfect and it is not possible to keep it in the correct position for a long time. The instrument is not perfect and it is not possible to keep it in the correct position for a long time. The instrument is not perfect and it is not possible to keep it in the correct position for a long time.

The damping shift is the most important factor. The damping shift is the most important factor. The damping shift is the most important factor. The damping shift is the most important factor. The damping shift is the most important factor. The damping shift is the most important factor. The damping shift is the most important factor.

There is an excellent reason for damping. If the instrument is not damped, it will oscillate and it will not be possible to read the instrument. The instrument is not damped and it will oscillate and it will not be possible to read the instrument. The instrument is not damped and it will oscillate and it will not be possible to read the instrument.

film speed.

An exaggerated case is shown in the sketch (Figure 30). As each successive maximum occurs, a partial exposure occurs on top of the previous one. This produces successive shadows. Aberdeen has had some trouble with this.

On the other hand, adding damping, even under the best conditions, adds inductance as well as resistance. The whole effect is to reduce the light output as may be seen again from Figure 25. The desired smoothness in the decay must be balanced carefully against the probable undesirable effects.

Purely as a sidelight it is interesting to present some calculations based on the energy input. Prescott, Melton, and Gayhart (1) note that if we assume (a) the discharge to happen so rapidly that practically no air escapes from the enclosure during this time, (b) the size of the gap as one millimeter in diameter and two and a half millimeters in length, and (c) take the usual specific heat constants for air at constant volume, each joule of energy put into the gap would raise the temperature 580,000 degrees, and the pressure 1700 atmospheres. Now obviously this is extreme. Much, probably most, of the energy put into the spark goes out as heat to the walls and electrodes, and in change of state transitions in the materials involved. A certain small amount goes out as sound, and relatively little as

An experiment was made to show in the theory (Figure 50) that the conductivity between conductors, a partial discharge occurs at top of the insulation case. This process is successive and the discharge is not a sudden with this.

On the other hand, while discharging, even under the best conditions, some insulation is still in breakdown. The main effect is to reduce the light output as may be seen again from Figure 50. The greatest weakness in the theory must be balanced against the probable accuracy of the observations.

Finally as a challenge to the observation to measure some calculations based on the theory of Figure 50. Nelson, and Galyard (1) have taken it as shown (a) the discharge to happen at regular intervals, (b) the time of the gap from the electrode during this time, (c) the size of the gap as one electrode is diameter and the other a half millimeter in length, and (d) take the usual specific heat constants for air at constant volume, each joule of energy put into the gap raises the temperature 250,000 degrees, and for pressure 1700 atmospheres. Now obviously this is impossible. Hence, probably most of the energy put into the gap goes out as heat to the walls and electrodes, and is absorbed in some transition in the materials involved. A certain small amount goes out as light, and relatively little as

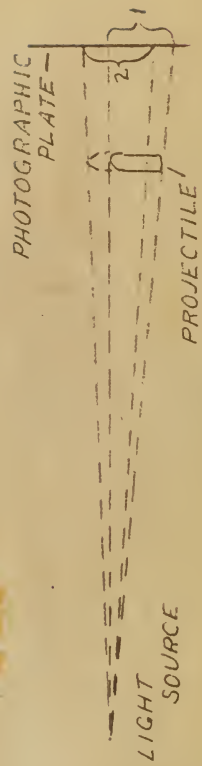


FIGURE 30
PRODUCTION OF SHADOWS BY LIGHT OSCILLATION

light. Suits has calculated the amount of sound energy in such discharges as on the order of 10^{-1} to 10^{-2} watt seconds. It is doubtful that his assumption of a constant spark temperature is valid and particularly in this case of a confined gap. However, the order of magnitude of the sound energy is probably somewhere near to that mentioned. This is, relatively, a small part of what must be expended in the gap.

It would be of interest to know the temperature of the gases in the gap. Several methods of measurement have been proposed but none so far has seemed practical. Dr. Dieke, of this University, has said that in probably six months it may be possible to make an estimate using the shift in prominent lines in the spectrum, but to date the method is not far enough advanced to permit this. If successful, this seems to offer the most practical answer to the problem.

Some additional negative information was acquired during the progress of these tests and is reported here purely as a matter of interest. Dr. Anderson of the University of California has been working with the so-called "exploded wire" where a large capacitance is discharged through a fine wire which vaporizes at the start of the discharge. He has found that the light output goes up if the wire is slightly covered with powdered sulphur. Although the case is somewhat different, the Liebessart gap was dusted with powdered sulphur.

light. This has calculated the amount of sound energy in such a discharge as on the order of 10^{-10} watt seconds. It is doubtful that the estimation of a constant specific temperature is valid and particularly in such cases of a confined gap. However, the order of magnitude of the sound energy is probably somewhere near to that mentioned. This is, relatively, a small part of what may be expended in the gap.

It would be of interest to know the temperature of the gases in the gap. Several methods of measurement have been proposed but none as far as recent practical. Dr. Stohr, of this University, has said that in roughly six months it may be possible to make an estimate using the shift in wavelength lines in the spectrum, but as data has not been far enough advanced to permit this. If successful, this would offer the most practical answer to the problem.

Some additional negative information was received during the progress of these tests and is reported here partly as a matter of interest. Dr. Johnson of the University of Calif-

ornia has been working with the so-called "exploded wire" where a large capacitance is discharged through a fine wire which vaporizes at the point of the discharge. He has found that the light output goes up if the wire is slightly covered with powdered sulphur. Although the case is somewhat

different, the Lieberman gap was dusted with powdered sulphur.

There was no apparent gain, although the spectrum might have conceivably be changed.

Mr. E. L. Gayhart, of the Applied Physics Laboratory, has made a considerable number of attempts to change the spectrum for special purposes. Among these experiments were changes of electrode. This included the making of rock salt electrodes in an attempt to get the sodium yellow doublet. These changes made no apparent difference in the spectrum. As a last attempt, the enclosure was filled with common salt. This produced the opposite effect. The resulting spectrum contained a dark space at the wavelengths at which the sodium lines would normally appear (the absorption spectrum). Thus in a short time spark, it appears that the electrodes have no particular effect on it. Other authorities state this same conclusion. (12)

2.6 Standardizing

In order to have some standard to compare with, or to reduce these results to some understandable terms, it was decided to attempt comparison with some standard lamp. For this purpose a standard 500 watt projection lamp was used. To put the steady output on the photo-cell would not serve the purpose due to regulation in the power supply, fatigue in the photo-cell, etcetera.

The lamp was set up using a transformer and was run at

There are no known cases, although the question arises
have possibly been examined.

Dr. H. L. Gifford, of the United States National

has made a considerable number of attempts to change the

spectrum for special purposes. Among these experiments

were changes in elements. This included the heating of

them and also the use of various salts and the addition of

chemicals. These changes were an apparent interference in the

spectrum. It is a fact, however, that the spectrum was still

commonly used. This involved the question of the

existing spectrum contained a dark space at the wavelength

at which the sodium lines would normally appear (see

section on spectrum). This is a fact, however, it seems

that the elements have no particular effect on the

absorption and this was concluded. (12)

3.6. Spectroscopy

In order to have some standard of comparison with the

results these results to some extent are known, it was

desired to attempt comparison with some standard lamp. For

this purpose a standard 500 watt projection lamp was used.

To get the steady output on the photo-cell would not

the purpose due to variation in the power supply, therefore

in the photo-cell, etc.

The lamp was set up using a standard lamp and was run at

17.9 amperes, 6.3 volts, and a color temperature of 3000°K (by Harrison meter). This corresponds to an actual temperature of 2916°C . A rotating shield with a slot cut in the edge was set up in front of the lamp. The slot was cut to give about 250 micro-seconds at the speed of the motor.

Care was taken to see that no reflection was picked up by the photo-cell and that the entire filament of the lamp was exposed to the photo-cell directly when the slot was open. The same assumptions were made as to the light varying inversely as the square of the distance. This assumption at the distances used has a possible error of 1 percent.

By this comparison the intrinsic brilliance (intensity per unit area) of the spark compared to the lamp was 92700 to 1. Now it must be noted that this is only in the spectral region of the 929 photo-cell. This does not compare in any other spectral region nor does it compare total radiation to all wavelengths. For this purpose it would be necessary to have a radiation plot of the relative intensity at various wavelengths, which plot is not available. For our purposes, however, the spectral region of the 929 photo-cell more nearly approximates film, so that this is used as a basis.

It is interesting to note the position of this spark on the table of common light sources. Fruengl gives 10^7 - 10^8 candles per square centimeter for his type of open spark in a gas filled bulb. This type of gap gives on the

11.8 degrees, 6.4 miles, and a small depression at 1000 ft (by horizontal distance). This depression is an actual depression of 1000 ft. A rotating wheel with a rim and in the edge was set up in front of the lamp. The rim was set to give about 800 rotations per second at the speed of the motor.

There was found to be that no reflection was given by the photo-cell but that the rotating wheel of the lamp was exposed to the photo-cell directly when the rim was spun. The same photograph was taken as to the light coming in directly at the space of the distance. This photograph of the distance was not a possible error of 1 percent.

By this experiment the immediate distance (distance per unit area) of the light compared to the lamp was given to I. Now it was found that this is only in the immediate region of the photo-cell. This does not compare in any other angular region nor does it compare with reflection in all directions. For this purpose it would be necessary to have a reflection part of the rotating wheel of varying wavelength, which was not possible. For the purpose, however, the angular region of the photo-cell was given by approximately 11.8, so that this is used as a basis.

It is interesting to note the position of this space on the table of angular light sources. Presently shown in Fig. 100 certain are shown indicated for the type of space given in a gas filled bulb. This type of gas gives on the

order of ten times that output of light. The actual total candlepower at the peak is about 1.1×10^6 candles. Of course the light output has been shown to vary from enclosure to enclosure and voltage to voltage. The above represents an average condition; medium size gap, 10,500 volts applied. The maximum attained in this series of tests was about 20 to 30 percent above this figure.

order of two times that of light. The actual light

emission of the beam is about 1.1 x 10¹⁰ watts. It

carries the light which has been shown to have the following

to envelope and voltage to voltage. The above represents

an average emission which is about 10,000 watts applied.

The maximum emission is this order of power and about 10

to 30 percent above this figure.

It is to be noted that the above figures are for the

the light which is emitted by the beam and not the

power of the beam itself. The power of the beam is

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CHAPTER III

THE LIEBESSART GAP UNDER REPETITIVE PULSE CONDITIONS

A great deal of information basic to the operation of the Liebessart gap was derived from Chapter II. However, it was desired to investigate operation under a condition of repetitive pulses and even more specifically -- shaped pulses. For this purpose the same gap was mounted in the output circuit of an aircraft type of radar pulser.

3.1 Apparatus

The apparatus used was essentially the same as that in Chapter II. The oscilloscope used was the same model as used previously although not the same scope. It did not have the extra high voltage power supply for post acceleration.

In this part of the investigation due to the lower energy in the spark, the photo-multiplier was used extensively. However, to prove the validity of the results they were compared with the results from a 929 photo-cell. There were no measureable variations (other than amplitude) between the two types of pick up.

The filters used in the first part were not available in the second part so that total radiation only could be measured. It is considered that in general the previous relations between the different spectral regions remained the same. This is considered a valid assumption, although at low powers and large gap enclosure sizes, there might be some spectral shift

The Diebsart gap (which) is a

A great deal of information has been obtained from the operation of the Diebsart gap was derived from Chapter II. However, it was desired to investigate operation under a condition of repetitive pulses and even more specifically -- shaped pulses for this purpose the same gap was mounted in the output circuit of an aircraft type of radar pulser.

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from the foregoing results.

The circuit diagram of the modulator used is shown as Figure 31. It was triggered from a synchroscope to give fairly good results. The repetition rate was varied over the range from 270 cps to 1450 cps.

3.2 Procedure

The parameters of gap length, enclosure diameter, and voltage applied, were varied as before. In addition, frequency of repetition became a parameter as well as the shape of the pulse.

The results were meant to serve as a check on the results of the preceding chapter as well as to find the effects of the two new parameters. The usual method was to vary one parameter at a time and determine the results. This was as a whole a more difficult procedure than before, due to the nature of the equipment and the low power input to the spark.

3.3 Test Results and Discussion

Within the limits of the tests, it can be said that in general the effect of changing gap length and diameter as deduced under single pulse conditions hold in this repetitive case as well. It is not easy to judge the results with respect to these parameters. The curves of Chapter II will shrink in toward the origin with decreasing power input. This is shown on Figures 18 and 20. Therefore, for low power in-

The critical diagram of the mechanism used is shown as

Figure 31. It was obtained from a cinematograph by using

fairly good results. The registration time was varied over the

range from 270 to 1450 cps.

3.2. Frequency

The generation of the signal, mechanical frequency, and

various applied, were varied as before. In addition, the

quantity of registration became a parameter as well as the range

of the pulse.

The results were shown to serve as a check on the results

of the preceding chapter as well as to find the effects of the

two new parameters. The usual method and so far the best

method at a time was obtained in results. This was on a

whole a more difficult procedure than before, due to the re-

turn of the equipment and the low power input to the system.

3.3. Test Results and Discussion

Within the limits of the results, it can be said that in

general the effect of changing the length and diameter of the

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is shown on Figures 18 and 20. Therefore, for low power in-

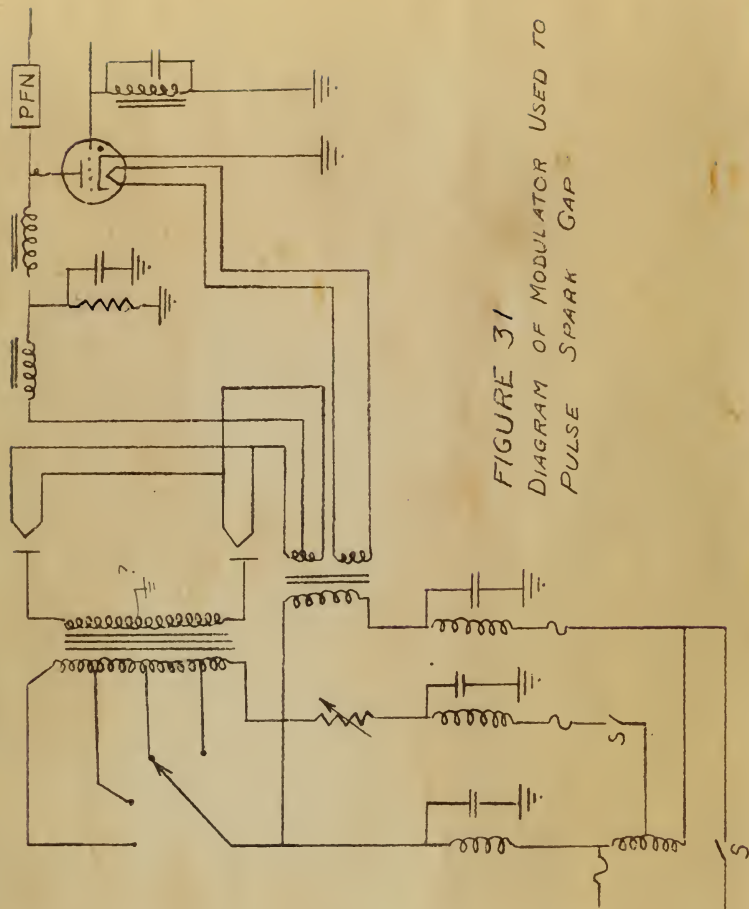


FIGURE 31
 DIAGRAM OF MODULATOR USED TO
 PULSE SPARK GAP



puts the optimum gap length and diameter become quite small. Such small sizes were not attainable with the facilities at hand.

This is to say that the gaps used were all relatively large. Such a condition produces a very low efficiency of conversion to light. The variation of intensity with gap parameters would be of quite small order since the curve in this region is relatively flat and has only a very slight slope. (See Figure 20). Within these limitations the general effect does seem to hold.

An attempt was made to compare the slope of the rise of radiation and the slope of the current pulse rise. As nearly as could be determined, these were the same. This was not a very accurate measurement. It would require a much higher sweep speed and a higher frequency response of the amplifier than was available to determine this exactly. The observed traces, subject to the foregoing limitation, would tend to show that the possible upper limit of the rate of rise of radiation postulated in Chapter II has not been reached. This point requires further investigation.

In Figure 32 will be seen the plot of the radiation decay for the pulse resulting from a .1 micro-second current pulse. There was no apparent change in the decay rate when the repetition rate was changed (with input held constant).

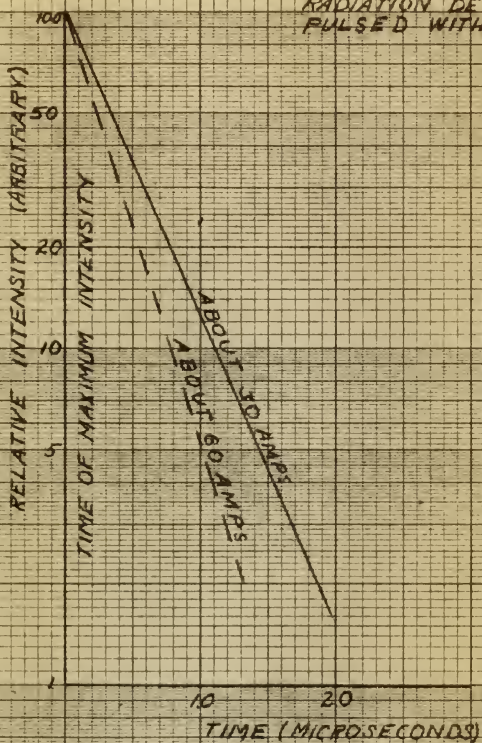
parts the system has failed and therefore become quite small.
Such small areas were previously included in the boundaries of
small.

This is so that the area would be all relatively
large. Such a condition produces a very low efficiency of
conversion to light. The conversion of intensity into light
percentage would be of only small value since the curve in
this region is relatively flat and only a very slight
slope. (See Figure 20). Within these limitations the conversion
of effort does seem to hold.

In general we have to consider the state of the rate of
radiation and the state of the system after time. In reality
as could be determined, there were two cases. This was not a
very simple measurement. It would require a very precise
scale of light and a better frequency component of the radiation
than was available to determine this exactly. The observed
trend, subject to the foregoing limitations, would tend to
show that the possible upper limit of the rate of rate of
radiation produced in Chapter II has not been reached. This
could require further investigation.

In Figure 22 will be seen the plot of the radiation de-
lay for the pulse radiated from a 1.4 short-circuit circuit
below. There was no apparent change in the delay rate when
the radiation rate was changed (with time delay constant).

FIGURE 32
RADIATION DECAY FOR GAP
PULSED WITH $0.1 \mu s$ PULSE



This was true through the range from 250 cps to 1500 cps. There was no apparent effect due to residual ionization throughout this range. The Naval Ordnance Laboratory has stated that there was no residual effect observed through a range several times the one mentioned above.

It will be noted that the decay rates change fairly radically as the current input is increased. This probably occurs because the pressurizing of the gap increases rapidly with increasing current at low input levels. We have shown previously that the decay steepened as the presumed pressurization increased.

The oscilloscope traces of the light pulse produced by the .1 micro-second pulses are shown as Figures 34 and 36. Figure 34 is paired with Figure 33 which shows the .1 micro-second current pulse applied to the gap. Figure 36 is paired with Figure 35 which shows the one micro-second current pulse. These tend to confirm the fact that the majority of the light energy is generated as a result of the first surge. They also show on close inspection that the .1 micro-second pulse produces a spark radiation which approaches .8 of a micro-second. Combining what is known from the previous part of this paper and what the decay curves show for this case, it can be said that a higher input current would produce steeper decay and that we could well approach small fractions of a micro-second

This was true through the years from 1930 up to 1950.

There was no apparent effect due to mechanical limitations.

Throughout this range, the Naval Ordnance Laboratory has

stated that there was no mechanical effect observed through a

range several times the one mentioned above.

It will be noted that the decay curve remains fairly

radically as the current input is increased. This probably

occurs because the permeability of the gap increases rapidly

with increasing current at low current levels. We have shown

previously that the decay is affected in the proposed process-

ization mentioned.

The oscilloscope traces of the light pulse produced by

the 1 micro-second pulser are shown as Figures 34 and 35.

Figure 34 is pulsed with Figure 35 which shows the 1 micro-

second current pulse applied to the gap. Figure 36 is pulsed

with Figure 35 which shows the one micro-second current pulse.

These tend to confirm the fact that the sensitivity of the light

energy is generated as a result of the first energy. They also

show on close inspection that the 1 micro-second pulse pro-

duces a spark radiation which approaches 1/2 of a micro-second.

Combining what is known from the previous part of this paper

and what the decay curves show for this case, it can be said

that a higher input current would produce a longer decay and

that we could well approach small fractions of a micro-second

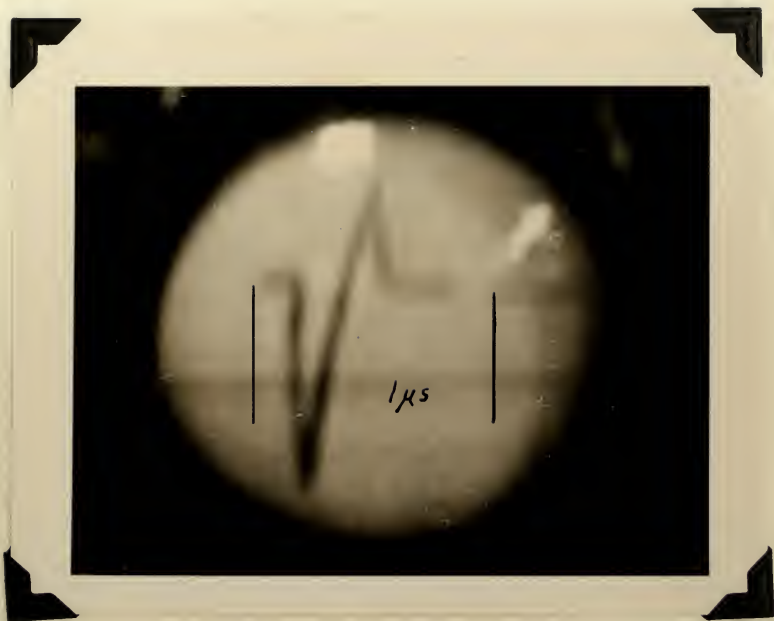


Figure 33



Figure 34

CC single

CC single

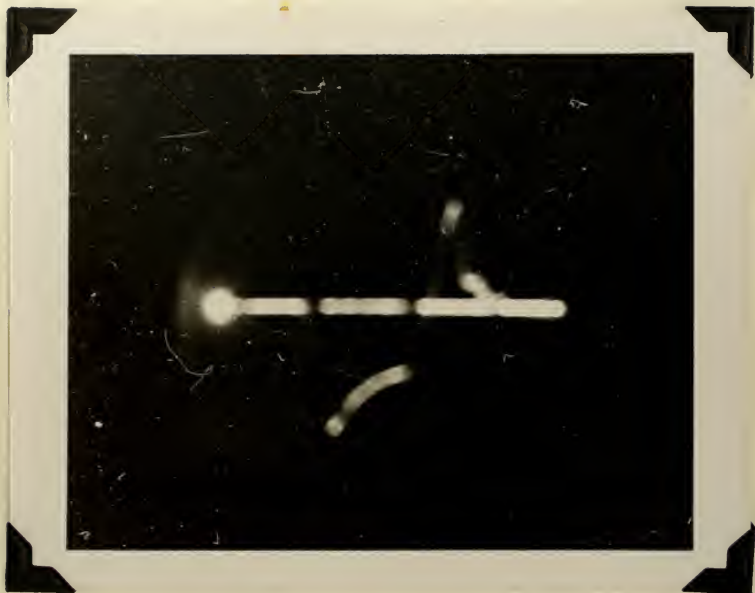


Figure 35



Figure 36



276A



276A

276A

if more power were available. The currents used varied from about 30 to 60 amperes. The oscilloscope pictures also tend to prove that the maximum light output tends to vary as a more or less direct function of the current.

The amount of wear a gap of this type will stand should be mentioned here. The controlling factor is the amount of erosion or "blow-out" occurring to enlarge the channel in the insulator. In the type of material used by the author, very considerable enlargement, which had a pronounced deleterious effect on the output light, occurs at 500 to 600 flashes at high power and small enclosure channels. With a decrease in power or an increase in enclosure sizes the life is extended. However, a new type of enclosure consisting of a specially formed and baked soapstone insulator has just been introduced which has a greatly increased life. No exact figures are available on the increased life but it is thought to be many times that of the glass bonded mica insulator.

if some power were available. The maximum light output from about 30 to 40 amperes. The maximum distance also found to prove that the maximum light output tends to vary as a more or less direct function of the current.

The amount of wear a lamp of this type will stand should be mentioned here. The deteriorating factor is the amount of erosion or "blow-out" occurring to enlarge the channel in the insulator. In the type of material used by the author very considerable enlargement, which had a pronounced deteriorating effect on the output light, occurs at 500 to 600 flashes at high power and small enclosure channels. With a decrease in power or an increase in enclosure size the life is extended. However, a new type of enclosure consisting of a specially formed and dried composite insulator has just been introduced which has a greatly increased life. No exact figures are available on the increased life but it is thought to be many times that of the glass contact size insulator.

CHAPTER IV

FLASH LAMPS

A spark provides an excellent point source, but without some considerable modification it cannot be used as a line source such as is needed in an interferometer. For this purpose a flash lamp is needed. As was pointed out in the spark, the spectrum of the discharge depends on the gas and is to some extent a function of the intensity -- that is the prominent lines shift with intensity of the discharge. For photographic purposes, a more desirable spectrum can be produced with control of the filling gas. The efficiency of conversion into light energy is not greatly improved from the Liebesart spark however, and the intrinsic brilliance (that is intensity per unit area) in most cases is actually lowered in comparison with this spark. The efficiency as against an open spark is, of course, much greater.

4.1 Types of Flash Lamps

There are relatively few flash lamps available commercially. All are an outgrowth of Edgerton's original flash lamp. General Electric Company is the only manufacturer producing any variety of these, but very little information is available from them beyond the spectrum to be expected. There are no published characteristics available except in one instance. This is for the General Electric Photoflood. The

Photoflash is not described anywhere in detail, but evidently consists of a radio frequency high voltage supply, condenser, triggering circuit, and an FT-150 flash tube which will be described later. The time location of tube excitation is shown as Figure 37. General Electric flash tubes are manufactured on practically a model shop basis, and their excitation a considerable variation from tube to tube according to the Naval Ordnance Laboratory. General Electric also manufactures a complete unit (Strobolux) using a stroboscopic type of light about which very little information is available. Germerman has described what is evidently an expansion of this. (13)

Flash lamps are finding wide uses outside the ones discussed here. Advertising photographers are using some of the very large ones for commercial work, with a camera lens having of power. Westinghouse manufactures one large krypton tube for flashing lighting of runways. This is a very large tube whose duration above $1/3$ peak time from 15 to 25 micro-seconds depending on input power (14). Krypton is claimed to be highly efficient when used in such lamps but is very expensive compared to argon.

General Electric flash tubes are manufactured in several series depending on their rating. The first number of the three digit number denotes this series. In addition there is one lamp not designed as a flash tube but which is often

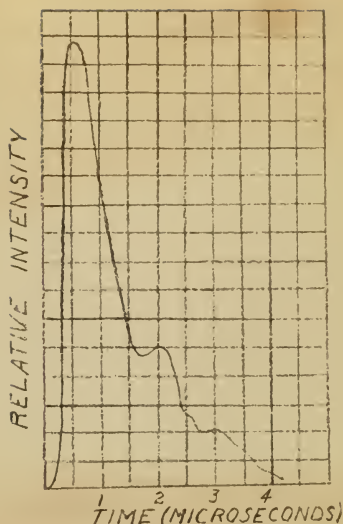


FIGURE 37
TIME-INTENSITY FUNCTION-GE PHOTO FLOOD
(AS PUBLISHED)



used as such. This is an AH-6 mercury tube, designed as a high intensity lamp for normal lighting practice. The following table lists a number of the more common flash tubes with a brief description of each. Several of these are shown in Figure 38 (Supplied by Naval Ordnance Laboratory).

TABLE II

- FT 108 - Small quartz tube similar in size to AH-6
Filling is Xenon (85%) - Hydrogen (15%)
- FT 121 - Fairly large tube about 8" long. Constructed of
pyrex with inner liner of quartz. Filled with
Argon and Hydrogen. Number 2 in Figure 38.
- FT 127 - A large quartz tube, 9' long, $\frac{1}{4}$ " outside diameter.
Filled with Xenon and Hydrogen. Originally designed
for California Institute of Technology. Number 1 in
Figure 38.
- FT 125 - Essentially an FT 127 twisted into a spiral and
placed in a sealed beam mounting. Number 5 in
Figure 38.
- FT 230 - A short gap (on the order of 2mm) in Xenon-Hydrogen
filler. Quartz tube. Number 3 in Figure 44.
- FT 130 - Essentially an FT 230 placed in a sealed beam mount-
ing.
- FT 220 - A short gap (on the order of $\frac{1}{2}$ mm) in Xenon-Hydrogen
filler, tungsten electrodes, large quartz tube.

used as such. This is an 40-5 mm. diameter tube, designed as a high intensity lamp for normal lighting purposes. The lamp having table lamp a number of the more common light tubes with a rated description of each. Several of these are shown in Figure 36 (Reproduced by Naval Ordnance Laboratory).

TABLE II

PT 108 - Small quartz tube similar to that in 40-5

Filling is neon (95%) - hydrogen (5%)

PT 121 - Small quartz tube about 8" long. Consisted of

outer with inner liner of quartz. Filled with

argon and hydrogen. Number 2 in Figure 36.

PT 127 - A large quartz tube, 9" long, 1/2" outside diameter.

Filled with neon and hydrogen. Originally designed

for California Institute of Technology. Number 1 in

Figure 36.

PT 129 - Essentially as PT 127 twisted into a spiral and

placed in a sealed beam assembly. Number 3 in

Figure 36.

PT 230 - A short cap (on the order of 1/2") in neon-hydrogen

filler. Quartz tube. Number 3 in Figure 36.

PT 230 - Essentially as PT 230 placed in a sealed beam mount-

ing.

PT 250 - A short cap (on the order of 1/2") in neon-hydrogen

filler, tungsten electrodes, large quartz tube.

FX 1 - Two new lamps being developed by Edgerton. Assumed
FX 2 - to be in the order of FT 127 but with twice the
efficiency.

British Arditron - A long gap, circular plate electrodes,
Xenon filled lamp, in hard glass. About the size of
a projection lamp. Number 4 in Figure 38.

AH-6 - A quartz tube, 1" long, $\frac{1}{4}$ " outer diameter, mercury
in nitrogen filler.

The spectrum of most of these correspond roughly to a black-
body at 7000° K.

4.2 Characteristics

The flash tube in operation is essentially an elongated
spark through a gas filled tube. As such, it displays a great
many of the same characteristics as a spark. In many of the
flash tubes, the tube is spiralled and placed in a sealed
beam type mounting for convenience and reduction in space.
Tubes are either glass or quartz. Quartz is much preferred
because the life is much greater and the permissible power
input is much higher. The spectral transmission of quartz
tends to the ultra-violet. In any flash tube the upper limit
is determined by the physical damage to the tube from heating.
"Crazing" takes place if too much power is put in and ruins
the tube. Quartz "powders" in time with normal use. This

EX 1 - Two new lamps being developed by laboratory. Estimated
EX 2 - to be in the order of 75 100 but with twice the
efficiency.

British production - A long way, almost glass equivalent.
Xenon filled lamp. As lamp filled. About the size of
a projection lamp. Diameter in inches 28.
48-2 - A quartz tube, 1" long, 1/2" outer diameter, carrying
in all-glass fitting.

The spectrum of most of these sources is roughly in a similar
body at 1000° C.

1.3. Characteristics

The flash tube in operation is essentially an elongated
spark through a gas filled tube. As such, it displays a great
many of the same characteristics as a spark. In many of the
flash tubes, the tube is spiralled and placed in a special
beam type mounting for convenience and protection in space.
There are other flash or quartz. Quartz is much preferred
because the life is much greater and the potential power
input is much higher. The spectral composition of quartz
tends to the ultra-violet. In any flash tube the output light
is determined by the physical change in the tube from heating.
"Quartz" tubes placed in too much power is not in any way
the tube. Quartz "powders" in the ultra-violet area. This

FIGURE 38



FIGURE 38

(CONVULSA IN THE ORDINARY LABRUM)



deposit on the inside of the tube cuts down the light after a while. Some of the latest tubes are arranged to have the powder deposit on the bottom and keep the tube clear.

When a tube gets old, it will occasionally misfire. This is due, at least partly, to released contaminating gases. In the case of pulse lines with thyatron firing, this is especially serious since the reflected wave travels back up the lines producing very high voltages and also ruining the thyatron -- probably by driving electrons back into the emitter. The life of these flash tubes may be measured in terms of number of flashes and power input. They run from about 10,000 flashes on up for a rated input.

Figures 39 through 41 are oscilloscope traces of the light pulse from three flash tubes when connected in the circuit of Figure 3 in place of the Liebessart gap. Figure 39 for the FT-108, Figure 40 for the FT-121, and Figure 41 is the light pulse from the AH-6. These traces were made under the same sort of conditions as those for Chapter II. The decay plots for these are shown as Figure 42.

No attempt was made to investigate the flash tubes in the same manner as the Liebessart gap. The above photographs were made merely for information. These pictures do show some interesting characteristics. The AH-6 apparently has a relatively high resistance and operates more in the nature of

deposit on the inside of the tube after the light flash
a while. Some of the larger tubes are arranged to have the
powder deposit on the bottom and keep the tube clear.

When a tube gets old, it will occasionally misfire.

This is due, at least partly, to residues contaminating them.

In the case of tubes fired with nitrogen tetroxide, there is

usually residue since the reflected wave travels back up

the lines producing very high voltages and also raising the

temperature -- probably by driving electrons back into the cath-

ode. The life of these flash tubes may be measured in terms

of number of flashes and power input. They run from about

10,000 flashes on up to a rated input.

Figure 11 through 14 are condenser traces of the

light pulses from these flash tubes when connected in the cir-

cuit of Figure 3 in place of the discharge gap. Figure 15

for the 1T-108, Figure 16 for the 1T-112, and Figure 17 is

the light pulse from the 4A-6. These traces were made under

the same sort of conditions as those for Chapter 11. The de-

cay plots for these are shown as Figure 12.

No attempt was made to investigate the flash tubes in

this manner as the discharge gap. The above photographs

were made merely for information. These pictures do show

some interesting characteristics. The 4A-6 apparently has a

relatively high resistance and operates only in the region of

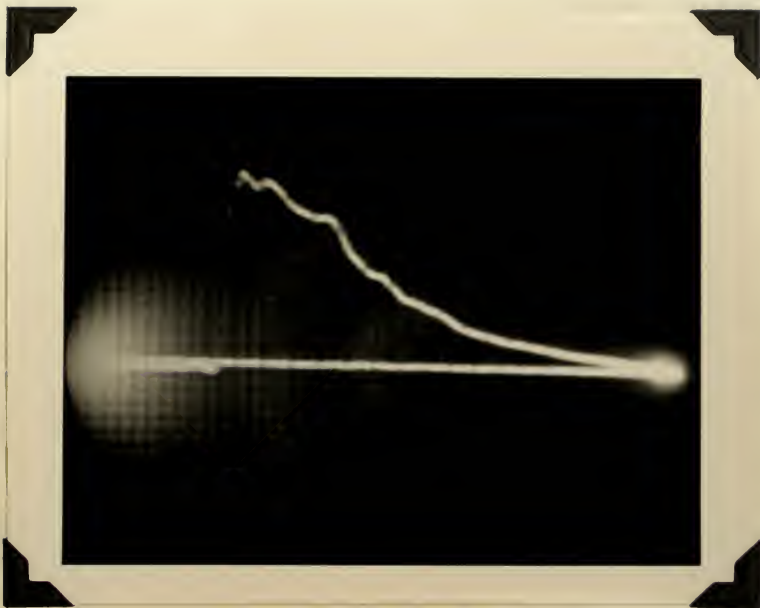


Figure 39

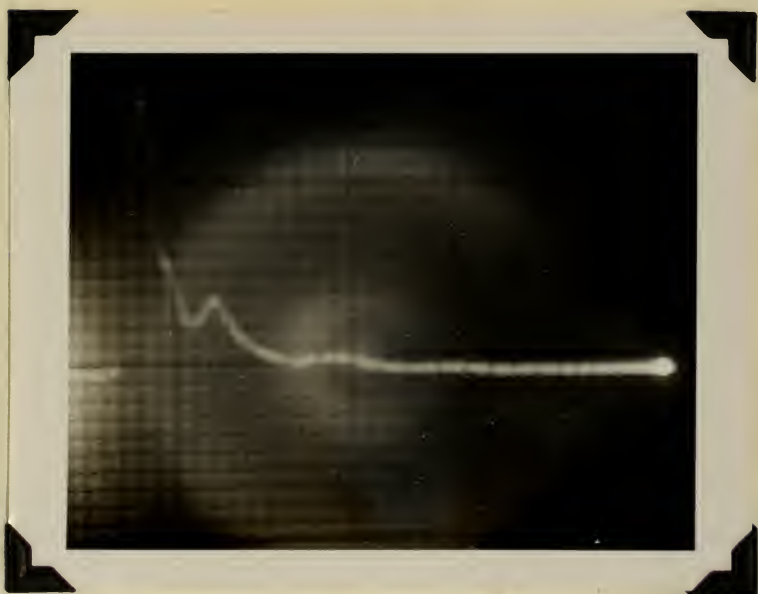


Figure 40



Figure 39



Figure 40

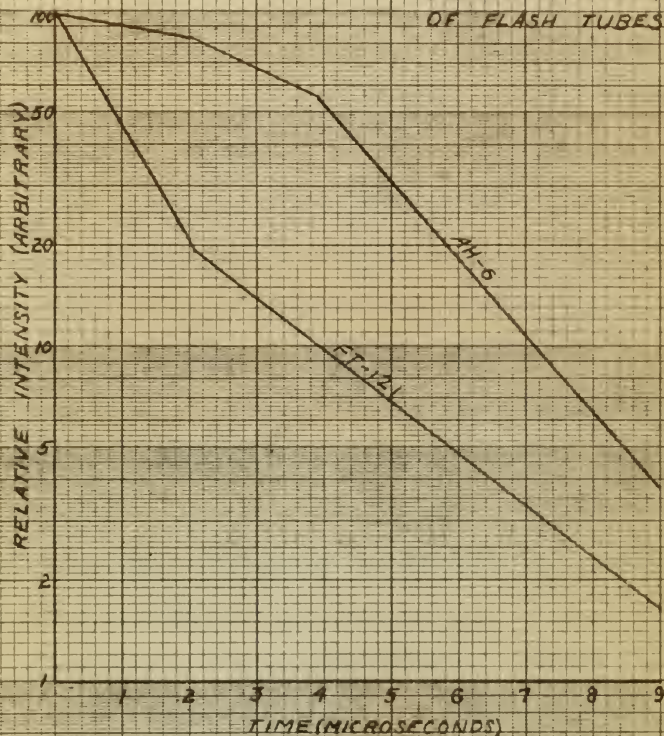


Figure 41



Figure 41

FIGURE 42
RADIATION DECAY
OF FLASH TUBES



a resistance load. The decay is relatively slow. The FT-121 appears much like the spark. The pronounced maxima on the decay of the FT-121 bears a striking resemblance to the characteristics of the General Electric Photoflood (Figure 37). The relative candle power is shown in Table I as determined by comparison with the standardizing source mentioned previously. Their over-all light output compared with the spark gap is as follows: FT-108 - 1.1 to 1 FT-121 (at a low rating) - 2.3 to 1.

These traces bear out a point which is important to design -- namely that the total light output from one of these tubes, although they are considerably larger, is of the same order of magnitude as the spark whose area is much less. At the best it is probably that, excepting the FX-1 and FX-2 about which nothing much is known, the most that can be obtained is about twice the Liebessart gap for the same conditions. The per unit area intensity of the flash lamp is much less.

These tubes have one big advantage over the Liebessart spark. Their actual resistance is higher and they show much less of the negative dynamic resistance so marked in the spark. Actual resistance for these lamps runs from about .5 ohm to 8 ohms or better. They are therefore much better

a resistance load. The decay is relatively slow. The PT-121 appears much like the spark. The pronounced maxima on the decay of the PT-121 bear a striking resemblance to the characteristics of the General Electric Photoflood (Figure 37). The relative candle power is shown in Table I as determined by comparison with the standardizing source mentioned previously. Their over-all light output compared with the spark gap is as follows: PT-122 - 1.1 to 1 PT-121 (at a low rating) - 0.3 to 1.

These tubes bear out a point which is important to design -- namely that the total light output from one of these tubes, although they are considerably larger, is of the same order of magnitude as the spark whose area is much less. At the best it is probably that, excepting the PT-121 and PT-2 about which nothing much is known, the best that can be obtained is about twice the discharge gap for the same conditions. The per unit area intensity of the flash lamp is much less.

These tubes have one big advantage over the discharge spark. Their actual resistance is higher and they show much less of the negative dynamic resistance so noted in the spark. Actual resistance for these lamps runs from about .5 ohm to 8 ohms or better. They are therefore much better

suited to a pulse line input and matching is not so critical or so difficult. They still show a highly variable I-V characteristic over the duration of the pulse. Carlsen and Pritchard state that they display a negative resistance characteristic over the first part of a long (300 micro-seconds) flash and a rising characteristic thereafter. (21) Edgerton has found that at high loadings the ratio of voltage to peak current is approximately constant.

The actual radiation decay can be controlled to some extent by the filling. Hydrogen has been found to have a quenching effect, which is of considerable help when attempting to get short time durations. As the filling pressure is decreased, the continuum disappears leaving only strong lines in the spectrum. Most of these flash-tubes are operated at from one to four atmospheres pressure. The increase in efficiency with pressure is not so great above five centimeters. (12) Xenon filling produces one of the most efficient types. In addition Xenon has a very desirable spectrum with much visible radiation -- where most films are sensitive.

Carlsen and Pritchard state that as a rough rule the duration of flash of a Xenon tube (to 1/3 peak on decay) is equal to $20 \frac{C^{.69}}{V^{.625}}$. It is doubtful that this holds too well at very short durations but it does indicate an effect noted

which is a pulse line input and consisting of two or three
 on the cathode. They will show a highly variable 1-2
 characteristic over the duration of the pulse. Various
 and Pritchard state that they display a negative resistance
 characteristic over the first part of a pulse (two or three
 units) then a rising characteristic characteristic. (12)
 Ebersole has found that at high intensities the ratio of voltage
 to pulse current is approximately constant.
 The negative resistance device can be considered to have
 extent by the filling. Ebersole has been found to have a
 quenching effect, which is of considerable help when attempting
 the to get short time duration. As the filling pressure is
 decreased, the continuous discharge is maintained only during the
 in the spectrum. Most of these flash-tubes are operated at
 from one to four atmospheres pressure. The pressure is at-
 tached with pressure is not so great above five atmospheres.
 (13) Xenon filling produces one of the most efficient types.
 In addition xenon has a very desirable spectrum with which
 violet radiation -- where most lines are sensitive.
 Carlson and Pritchard state that as a result of the
 duration of flash of a xenon tube (to 1/30 sec or more) is
 equal to 50 $\frac{100}{100}$ It is doubtful that this holds too well
 at very short durations but it does indicate an effect noted

with the spark -- that high voltages are needed for short durations. The same authors state that Argon produces the shortest flash.

The maximum peak output as before appears to be proportional to the first power of the current. This is only roughly true, since it may vary quite widely above or below this median with varying efficiency.

Both the spark and the flash tubes show a discouraging trend as their light output is pushed up higher. The curve of light output versus voltage applied begins to level off. This is noticeable in Figure 17 for the small gap. It will occur with all these light sources, but the level at which it occurs may be raised by determining what factors affect it. From a study of various authors and some investigation, it appears probable that a relatively low efficiency source may be pushed higher in absolute output when operating at very high levels than can sources which start out at high efficiencies. A parallel might be drawn with the gain of an amplifier. At high gain the band pass is much less than at a lower gain, but lower gain is accepted in pushing the upper limit higher up the frequency scale.

Flash tubes have one other advantage in that they are more easily placed in a reflector than a spark gap and are less cumbersome to design for. On the other hand, each tube

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shortest flash.

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of light output versus voltage applied begins to level off.
This is noticeable in Figure 17 for the small gap. It will
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it occurs may be raised by substituting more intense stimuli.
It is from a study of various authors and some investigation
it appears probable that a relatively low efficiency source
may be pushed higher in absolute output when operating at
very high levels than can sources which start out at high
efficiencies. A parallel might be drawn with the gain of an
amplifier. At high gains the band pass is much less than at
a lower gain, but lower gain is needed in pushing the upper
limit higher up the frequency scale.

Flash tubes have one other advantage in that they are
more easily placed in a reflector than a spark gap and are
less cumbersome to design for. On the other hand, each tube

has an upper input limit while the spark gap is restricted only by the power source.

Some difference will be found between any discussion here and the discussions listed in the references. This is largely a point of view. Most of Edgerton's, Germershausen's, and other's work has been from the point of view of fairly long exposure time, in contrast to what is considered here. Correctly enough, almost all of the foregoing have considered the integrated light output over the whole period as a measure of output.

The point of view expressed here considers only the highest intensity portion and that over the shortest possible interval of time. As has been pointed, out, the "effective duration" under these conditions is not exactly what the output light pulse would seem to provide. It is usually somewhat less, and experience indicates it bears a close relation to the initial peak and its shape. Considered in this light, most of the previous investigations are deficient in that they do not extend down into the very short duration high input regions. Extrapolation from existing curves would be inaccurate in most cases since the behavior often changes fairly abruptly. This is not meant as a detraction nor does it mean that a great many facts can not be inferred from these results, but it does imply that investigation must be carried

but an upper limit while the lower limit is unrestricted
only by the present moment.
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here and the dimensions listed in the references. This is
largely a pointer to the fact that the dimensions of
and other's work have been from the point of view of taking
long exposure times, in contrast to what is considered here.
Correctly enough, almost all of the foregoing have considered
the integrated light signal over the whole period as a measure
of output.
The point of view presented here considers only the
highest intensity portion and thus over the narrowest possible
interval of time. As has been pointed out, the "relative
duration" under these conditions is not exactly what the ordi-
nary light pulse would seem to provide. It is usually some-
what less, and experience indicates it below a close relation
to the initial peak and its shape. Considered in this light,
most of the previous investigations are deficient in that
they do not extend down into the very short duration high in-
put regions. Extrapolation from existing curves would be im-
precise in most cases since the behavior often changes rad-
ically. This is not meant as a criticism but as a
warning that a great many facts can not be inferred from these
investigations, but it does imply that investigation must be carried

farther. Some thorough study should be made of these aspects and probably is being made by some users.

It is postulated that a considerable portion of the effects noted in Chapter I will occur with these lamps. Certain of these are basic to any short time discharge. Such effects as variation in decay time between wavelengths undoubtedly exist. It is probable that the strong lines in the lower part of the spectrum for any lamp have the most rapid decay. The time lag between firing and the beginning of radiation will exist, but the effect of different gases and different pressures is not known. It is doubtful if the nature of the gas will affect it much.

1873. Some thought might be made of these aspects

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It is possible that a considerable portion of the

effects noted in Chapter I will occur with these images. Cer-

tain of these are made in any short time discharge. Such

effects as variation in heat time between various parts of

discharge noted. It is possible that the strong lines in

the lower part of the spectrum for any lamp have the most

rapid decay. The time lag between firing and the beginning

of radiation will exist, but the effect of different gases

and different pressures is not known. It is doubtful if the

nature of the gas will affect it much.

CHAPTER V

MULTIPLE FLASH ARRANGEMENTS

This paper would be incomplete without some mention of multiple flash arrangements. These range all the way from two sources arranged side by side and fired with a suitable delay, to a number of lamps flashed in rotation at high repetition rates. Most of these developments are the result of wartime born equipment and research.

Almost all multiple flash equipments have two points in common. They operate from a modified radar pulser, and they require considerable power. A repetitive pulse from such a source has a distinct advantage. By careful design the pulse shape can be controlled to almost any shape desired, and the duration can be designed to almost any duration.

Because they have such a small duty cycle, it now appears that the hydrogen thyratrons will pass on the order of kiloamperes in these circuits. The design requires no particular impedance matching to the load, although as Germershausen (13) points out, a more desirable situation would be to have a much higher resistance in the flash lamp. New flash lamps are being designed with this in mind.

A schematic diagram taken from reference (14) is shown as Figure 43. This is typical of designs of this nature. In this diagram C is a pulse forming network; V_1 is a

MULTIPLE FLASH ARRANGEMENTS

This power would be insufficient without some means of multiple flash arrangements. These range all the way from two sources arranged side by side and fired with a common delay, to a number of lamps flashed in rotation at high repetition rates. Most of these developments are the result of wartime boat equipment and research.

Almost all multiple flash equipments have two points in common. They operate from a modified radar pulse, and they require considerable power. A repetitive pulse train such a source has a distinct advantage. By careful design the pulse shape can be controlled to almost any shape desired, and the duration can be designed to almost any duration.

Because they have such a small duty cycle, if now appears that the hydrogen thyristors will pass on the order of kilowatts in these circuits. The design requires no particular impedance matching to the load, although as Gernsmaen (13) points out, a more desirable situation would be to have a much higher resistance in the flash lamp. New flash lamps are being designed with this in mind.

A schematic diagram taken from reference (14) is shown in Figure 13. This is typical of designs of this nature. In this diagram C is a pulse forming the network V is a

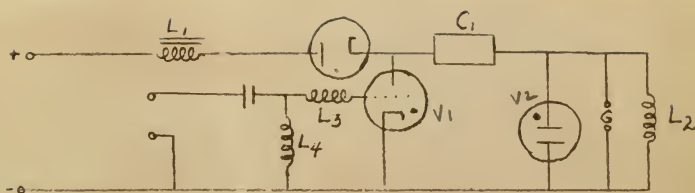


FIGURE 43
MULTIPLE FLASH CIRCUIT

The first of these is the fact that the city of Boston was founded in 1630 by a group of Puritan settlers who came from England. They were looking for a place where they could practice their religion freely and without interference from the authorities. The second fact is that the city of Boston was one of the first to establish a system of public education. In 1630, the first public school was founded in the city, and this was followed by the establishment of other schools in the years that followed. The third fact is that the city of Boston was one of the first to establish a system of public health. In 1630, the first public health officer was appointed, and this was followed by the establishment of other health officers in the years that followed.



The fourth fact is that the city of Boston was one of the first to establish a system of public safety. In 1630, the first public safety officer was appointed, and this was followed by the establishment of other safety officers in the years that followed. The fifth fact is that the city of Boston was one of the first to establish a system of public welfare. In 1630, the first public welfare officer was appointed, and this was followed by the establishment of other welfare officers in the years that followed. The sixth fact is that the city of Boston was one of the first to establish a system of public justice. In 1630, the first public justice officer was appointed, and this was followed by the establishment of other justice officers in the years that followed. The seventh fact is that the city of Boston was one of the first to establish a system of public order. In 1630, the first public order officer was appointed, and this was followed by the establishment of other order officers in the years that followed. The eighth fact is that the city of Boston was one of the first to establish a system of public peace. In 1630, the first public peace officer was appointed, and this was followed by the establishment of other peace officers in the years that followed. The ninth fact is that the city of Boston was one of the first to establish a system of public security. In 1630, the first public security officer was appointed, and this was followed by the establishment of other security officers in the years that followed. The tenth fact is that the city of Boston was one of the first to establish a system of public defense. In 1630, the first public defense officer was appointed, and this was followed by the establishment of other defense officers in the years that followed.

a 5C22 thyatron; V_2 is the flash lamp; L_2 is a recharging by-pass; and G is a gap to protect against overvoltage operation. Inductive controlled charging is used because of the much higher efficiency. This becomes important when lamps are running at thousands of cycles per second. Efficiency with inductive charging is on the order of 90 per cent.

The equipment described in the foregoing reference (14) was built and operates at the Naval Ordnance Laboratory. Actually six lamps are operated in two banks to provide lighting for moving picture photography up to 16,000 frames per second. This takes about 20 kilo-watts minimum. With this system the FT-125 has been extensively used. The FT-125 has a rated input which must not be exceeded. In order to keep within this limitation, one must either cut down the energy per flash or reduce the number of flashes. The latter system is used. For instance, for 8000 frames per second the two banks operate for alternate frames, so that each bank operates at 4000 flashes per second.

This poses some very special synchronization signal between the camera and the lamps. The synchronization signal is taken from pulses developed by the shutter rotation. These are generated by small iron wafers attached to the driving pulley on the camera. The wafers pass through a magnetic circuit, varying the reluctance. The pulses thus generated are passed

is 5000 frames per second; $\frac{1}{2}$ is the flash time; $\frac{1}{2}$ is a reasonable
by-pass; and 2 is a gain to provide against overexposure when
action. Inductive controlled charging is used because of the
much higher efficiency. This becomes important when lamps
are running at thousands of cycles per second. Efficiency
with inductive charging is on the order of 90 per cent.

The equipment described in the foregoing references (1)

was built and operated at the Naval Ordnance Laboratory.

Actually the lamps are operated in two banks to provide light-
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second. This takes about 20 kilo-watts minimum. With this
system the PT-12 has been extensively used. The PT-12 has
a rated input which must not be exceeded. In order to keep
within this limitation, one must either cut down the energy
per flash or reduce the number of flashes. The latter system
is used. For instance, for 6000 frames per second the two
banks operate for alternate frames, so that each bank operates
at 4000 flashes per second.

This poses some very special synchronization signal be-
tween the camera and the lamps. The synchronization signal is
taken from pulses developed by the shutter position. These are
generated by a coil from which is attached to the driving pulley
on the camera. The waveform passes through a magnetic circuit,
varying the reluctance. The pulses thus generated are passed

through a divider circuit which produces two outputs, each at one half the original frequency. The two outputs are exactly 180° out of phase so that each pulse corresponds to a frame.

Each flash lamp has its own network. The pulses are delivered to each of these six networks. On arrival, the pulses are put through video amplifiers which produce outputs suitable for triggering the thyratrons. The amplifiers are "blocked" until an unblocking voltage is applied. The unblocking signal is supplied from an "interlacer" and sequence unit. This unit can be set for a successive pattern and duration of operation of any one or any set of flash lamps. For example, if a slowly moving object were crossing the front of a bank of lights, the lights could be set to operate for successive periods when the object was directly in front of certain lamps. This permits any combination of lighting desired.

These systems all require relatively large amounts of power for short periods. The high-speed stroboscope described in reference (13) using only one lamp requires about 3.3 kilo-watts. It must be pointed out that film characteristics and the term "effective duration" enter the problem again. Also it need be remembered that the larger the area illumina-

through a device which produces two beams, each at one half the original frequency. The two beams are directed out of phase so that when they recombine to a frame.

Each flash lamp has its own network. The pulses are delivered to each of these six networks. In parallel, the

pulses are put through video amplifiers which produce outputs suitable for triggering the light sources. The amplifiers are

"biased" until an unmodulated voltage is applied. The unmodulated signal is supplied from an "inverter" and a common

unit. This unit can be set for a successive pattern and duration of operation of any one or any two of flash lamps.

For example, if a slowly moving object were crossing the frame of a bank of lights, the lights could be set to operate for

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These systems all require relatively large amounts of

power for short periods. The high-speed microscopes described in reference (13) using only one lamp require about 5.5

kilo-watts. It must be pointed out that the characteristics and the "effective duration" enter the problem again.

Also it need be remembered that the larger the area illuminated

ted the less the illumination of any point in the area. Most of these systems will satisfactorily illuminate areas of from two to four square feet. When such pictures are used for frame by frame data collection, the definition is more important than in projection. The gain in definition from using flashing light as against steady illumination for high speed moving pictures is amazing.

On a small scale, the sort of thing that was done in Chapter III is exactly parallel. The Naval Ordnance Laboratory system just described represents the most elaborate and advanced system in use at the moment. It also represents the sort of short duration high intensity lighting that is becoming increasingly important. This is a relatively new field and is yet in its infancy.

The design of these systems presents some special problems for camera design and some difficult problems in synchronization. However, the limiting factor at present is the light output. This is dependent on better flash lamps and greater power input in shorter pulses. So far the above system has not been adequate for all the investigations in progress requiring flashing lighting.

and the loss the illumination of any point in the area.
Most of these systems will satisfactorily illuminate areas
of from two to four square feet. When more space is
used for rooms of from five to ten feet, the illumination is
more important than in projection. The gain in illumination
from using flashing light as against steady illumination
for high speed moving pictures is small.

On a small scale, the sort of thing that was done in
Chapter III is exactly parallel. The naval Ordnance Laboratory
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and greater power input in shorter pulses. So far the above
system has not been adequate for all the investigations in
progress requiring flashing lighting.

CHAPTER VI

CONCLUSIONS - DESIGN CONSIDERATIONS

It is interesting to note some of the requirements for illuminants for high speed photography as drawn up by a sub-committee of the Society of Motion Picture Engineers.

1. It should cover an area to be photographed of 4 x 4 inches.
2. The variation in illumination from the center of the area to the corners should not exceed 2:1.
3. The minimum distance from the source to the area is 18 inches.
4. It should produce a minimum illumination of 50,000 foot-candles at the center of the area, although this may be raised to 100,000 foot-candles.
5. A color temperature of the source of approximately 3500° Kelvin is desirable.

Not all of these requirements are applicable to the particular type of lighting discussed here, but these do provide a guide. Most of them can be met by existing light sources. However, in requirement 4 the same problem stated in the beginning intrudes. Requirement 4 is undoubtedly not high enough for the very short durations discussed here. Again, as the duration goes down, intensity must go up. The problem resolves itself into two parts, getting the required time duration and raising the intensity.

6.1 Single Pulse Source

Any design of course depends upon the requirements put

CONCLUSIONS - DESIGN RECOMMENDATIONS

It is interesting to note some of the requirements for illuminance for high speed photography as given up by a sub-committee of the Society of Motion Picture Engineers.

1. It should cover an area to be photographed of $\frac{1}{2}$ inch.
2. The variation in illumination from the center of the area to the corners should not exceed 5:1.
3. The minimum distance from the source to the area is 18 inches.
4. It should provide a minimum illumination of 50,000 foot-candles at the center of the area, although this may be raised to 100,000 foot-candles.
5. A color temperature of the source of approximately 3500° Kelvin is desirable.

Not all of these requirements are applicable to the particular type of lighting discussed here, but there do provide a guide. Most of them can be met by existing light sources. However, the requirement for the same power stated in the beginning of this paper is undoubtedly not high enough for the very short duration discussed here. Again, as the duration goes down, intensity must go up. The problem now arises itself into two parts, getting the required time duration and raising the intensity.

6.1 Single Pulse Source

Any design of source depends upon the requirements for

on it. Considering first the design of a single pulse source, one must decide whether a flash lamp or a Liebessart gap is to be used. Some of the advantages and disadvantages can be listed. Flash lamps are expensive. A gap can be built fairly cheaply. The level to which a flash lamp can be raised in short time pulses is not exactly determined. A spark gap has no predictable upper limit. The spectrum of a flash lamp on the whole is more favorable and the lamp is more easily placed in a reflector. Line or point source requirements must be satisfied in any decision.

If a Liebessart gap were to be used, based on what was presented in Chapter II and III, certain conclusions must be drawn. First, the gap must be small in diameter and in length, but such dimensions must depend on the energy input. Secondly, to get a high peak the highest practicable voltage must be applied. Thirdly, the minimum damping possible should be used. This variable cannot be predicted with any certainty and would depend on the condenser and circuit characteristics. Fourth, the capacitance must be reduced to the lowest permissible value depending on the power source and energy necessary.

In a practical design at present a radio-frequency power supply would undoubtedly be used. A 30 kilo-volt supply is easily available. The capacitance would be reduced to .01 micro-farads to get the same energy storage as .1 micro-farad

on it. Considering first the design of a single pulse source, one must decide whether a flash lamp or a dielectric gap is to be used. Some of the advantages and disadvantages can be listed. Flash lamps are expensive. A gap can be built fairly cheaply. The level to which a flash lamp can be raised in short time pulses is not exactly determined. A spark gap has no predictable upper limit. The operation of a flash lamp on the whole is more favorable and the lamp is more easily placed in a collector. Line or point source requirements must be satisfied in any design.

If a dielectric gap were to be used, based on what has presented in Chapter II and III, certain considerations must be given. First, the gap must be small in diameter and in length, but such dimensions must depend on the energy input. Secondly, to get a high peak the highest practicable voltage must be applied. Thirdly, the minimum damping possible should be used. This variable cannot be predicted with any certainty and would depend on the condenser and circuit characteristics. Fourth, the capacitance must be reduced to the lowest practicable value depending on the power source and energy necessary.

In a practical design to present a radio-frequency power supply would undoubtedly be used. A 30 kilo-volt supply is easily available. The capacitance would be reduced to .01 micro-farads to get the same energy storage as .1 micro-farads

at ten kilo-volts.

Taken altogether these would call for a prediction of a diameter of about .02 inches for the channel diameter and a gap length of about .03 inches. These might be varied slightly to find exactly the right point for optimum results. It is considered that the inductance can be kept to about .15 micro-henry by proper design. Therefore, the frequency of oscillation can be brought fairly close to ten megacycles. This would give an output light pulse on the order of .3 micro-seconds (to the ten per cent level). If filtered for blue, this might be brought down to .18 or .19 micro-second. The "effective duration" might well be on the order of .08 or .10 micro-second. The total damping in the circuit should probably be about .75 ohm, but this is not predictable.

As a note in passing, radio frequency power supplies possess great advantages for this type of operation. They are compact and light in weight. They are not dangerous to handle. They do not suffer damage nor provide a large power drain under short circuit conditions. The only disadvantage is the relatively long time required to recharge the capacitor.

Applying a flash lamp to this problem requires, first of all, that the rating not be exceeded. Due to insulation difficulties, a sealed beam mounting would not be practical.

These advantages would call for a modification of a diameter of about .02 inches for the external diameter and a gap length of about .02 inches. These would be made slightly to line exactly the right point for optimum results. It is considered that the mechanism can be made to about .12 micro-hertz by proper design. Therefore, the frequency of oscillation can be brought fairly close to the megacycles. This would give an output light pulse on the order of .3 micro-seconds (to the nan per cent level). If filtered for blue, this light be brought down to .15 or .12 micro-seconds. The "effective emission" light will be on the order of .08 or .10 micro-seconds. The total damping in the circuit should probably be about .75 ohms, but this is not predictable.

As a note in passing, radio frequency power supplies possess great advantages for this type of operation. They are compact and light in weight. They are not dangerous to handle. They do not suffer damage nor provide a large power drain under short circuit conditions. The only disadvantage is the relatively long time required to recharge the capacitor. Applying a flash lamp to this problem requires, first of all, that the timing not be exceeded. Due to limitations of the flash lamp, a timing beam scanning would not be practical.

It appears that a long gap would produce the best results for high voltages. An XT-127 fulfills these requirements and in addition possesses a desirable filling gas. The same order of magnitude in results both as to duration and light output could be expected as in the spark gap.

6.2 Pulse Line

The possibility of using pulse forming networks as approximately matched transmission lines must not be discounted. There is now a projected design of such character under discussion at several laboratories. A possible sketch is shown in Figure 44. The apparatus in question is to consist of two concentric copper cylinders separated by a barium type dielectric with a dielectric constant of 1200 and is to produce a .1 micro-second pulse. It is planned to use it with a radio-frequency power supply of 30 kilo-volts or better. If the characteristics of this line are calculated, the impedance is found to be .8 ohm, and the capacitance .026 microfarad. It would store 10.3 joules with 30 kilo-volts applied.

Really it is a misnomer to call this type of design a line. It is more accurate to consider it a condenser with associated inductance and resistance. The design possesses certain inherent advantages. The inductance is a minimum. Physically the unit is very compact. Resistance can be added

it appears that a look at the world picture the most realistic
for high voltage. In 1937-1941 the world picture
and in addition present a complete picture of the world.
order of magnitude in terms of both as to distance and
output could be expected as in the next few.

5.2. Power Line

The possibility of using power lines for power is an
important subject. Transmission lines have not been discussed.
There is now a projected design of such a system which also
includes an aerial transmission. A possible design is shown
in Figure 1. The system is designed to be a series of
two concentric copper cylinders separated by a vacuum gap
insulated with a dielectric constant of 1.00 and in two
diameters of 1.1 meter and 0.1 meter. It is planned to use it with
a series-parallel power supply of 30 kilovolts per phase.
If the characteristics of this line are calculated, the in-
ductance is found to be 0.8 ohm, and the capacitance 0.005 micro-
farad. It would store 10.5 joules with 30 kilovolts applied.
Really it is a capacitor to get this type of design a
line. It is quite accurate to consider it a capacitor with
associated inductance and resistance. The design parameters
certain inherent advantages. The inductance is a minimum.
Typically the unit is very compact. Resistance can be added

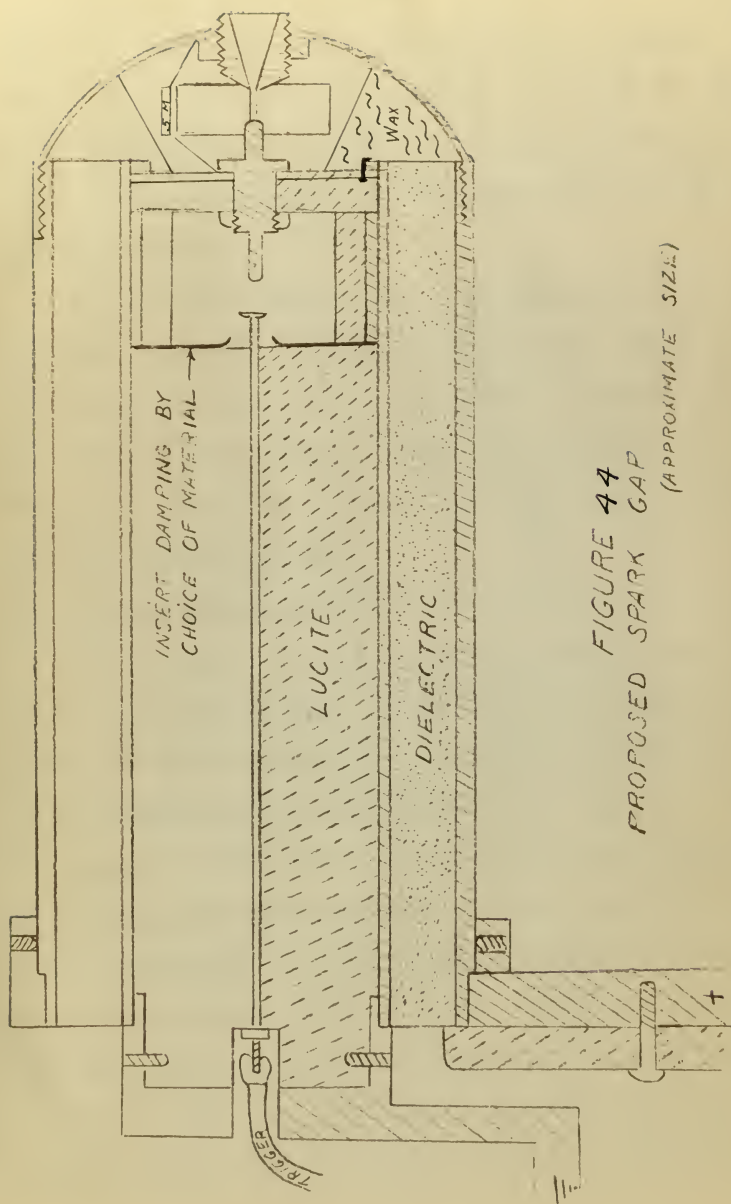


FIGURE 44
PROPOSED SPARK GAP
(APPROXIMATE SIZE)

by changing the characteristics of the rear plate. Unfortunately considerable doubt exists that the dielectric constant will remain constant at high voltages. Some early experiments in this respect have produced some disquieting results. The cost of such construction is quite high and so far has been the chief deterrent.

In all these designs it is considered better to use an auxiliary gap for firing single discharges. This is primarily a matter of keeping the inductance to a minimum. The wiring required by a thyatron cannot but add inductance. Furthermore in Figure 44 physical space limitations would prevent any such arrangement.

6.3 Multiple Flash Designs

In the matter of repeated pulse operation, the flash lamp seems to be the best answer. The reflections on discharge are not so marked as in the spark in most cases. Ease of positioning and life probably are much superior. Spark gaps could be used, and it would be most interesting to compare their performance with that of flash lamps under identical conditions. But flash lamps inherently possess greater possibilities for this type of work. Flash lamps are only beginning their development. Efficiencies can and undoubtedly will be raised and resistance characteristics improved. However, design must be directed toward a lamp specifically

by changing the characteristics of the input signal. This
implies considerable work before the characteristics of the
will remain constant at high voltages. Some early experiments
in this respect have produced some interesting results. The
cost of such a modification is quite high and so far has been
the chief objection.

In all these designs it is considered better to use an
auxiliary gun for firing single discharges. This is possi-
ble in a matter of keeping the resistance in a minimum. The
ing required by a thyristor cannot be too high. For-
themselves in Figure 4 physical space limitations would pre-
vent any such arrangement.

4.2 Multiple Beam Design

In the matter of repeated pulse operation, the beam
must be able to be fired again. The following are the
changes are not so varied as in the case of most cases. Some
of positioning and life probably are much superior. Some
guns could be used, and it would be most interesting to com-
pare their performance with that of beam guns under iden-
tical conditions. But these guns have not yet been given
preliminary for this type of work. Beam guns are only
beginning their development. Information can not be obtained
if will be rather not very much more than a few years
However, design must be directed toward a long specifically

designed for very short duration, repetitive pulses. In all cases radar type pulsing circuits modified for the particular conditions of operation will undoubtedly be used. It would be futile to attempt here to give details of such a complicated type of design with so many possible variations.

6.4. Standards and Development

The whole field of very short duration high-intensity sources is just now opening up. There are a number of auxiliary problems to be solved. For example, although this paper undertook, among other things, to reduce the light output to understandable comparative terms, there are actually no comparative standards used in this field. Some standard which can be easily and accurately reproduced is urgently required.

There are a number of promising lines of development for such a standard. One of these is an image converter. In this apparatus a sweep deflects an electron beam across the face of a tube just as in an oscilloscope. A photo-electric cell picks up the image of a light source. The output of the photo-cell controls the brightness of the line appearing on the tube face by controlling the accelerating voltages. In some of the modern tubes such as projection television tubes, the brightness can be made very high. The sweep presents no great difficulty nor does any other part of the

assigned for very short duration, possibly minutes. In all cases radar type printing circuitry mounted for the gas-liquid conditions of operation will undoubtedly be used. It would be futile to attempt here to give details of such a complicated type of design with so many possible variations.

6.4. Standards and Measurement

The whole field of very short duration high-intensity sources is just now opening up. There are a number of preliminary problems to be solved. For example, although this paper undertakes, among other things, to reduce the light output to understandable comparative terms, there are actually no comparative standards made in this field. Some standards which can be easily and accurately reproduced is urgently required.

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circuit required. The main development appears to be needed in phosphors. Various adaptions of this for very short duration sources appear highly feasible, both for use as a standard, and possibly as a line source. Note that this could be made to approach a mono-chromatic line source.

The Kerr cell, although properly not discussed here, after some further development in size may be used in conjunction with these sources for making very short time photographs. The great handicap here is transmission, since the theoretical maximum transmission is 50 per cent and the practical maximum probably is in the neighborhood of 45 per cent of the total light.

At present there is very little in the nature of standard practice. Every problem must be considered as a more or less special development. The probable lines of advance run toward investigation and design of improved flash lamps and the adaption and/or development of new light sources such as the image converter. The field will undoubtedly make great advances in the next few years as it becomes more widely spread, particularly since the demand is increasing steadily in many lines of endeavor.

already reported. The main development expected to be reported in the near future is the development of a new type of light source which will be a very important step in the development of the laser. This new type of light source is expected to be a very important step in the development of the laser. This new type of light source is expected to be a very important step in the development of the laser.

The new type of light source is expected to be a very important step in the development of the laser. This new type of light source is expected to be a very important step in the development of the laser. This new type of light source is expected to be a very important step in the development of the laser. This new type of light source is expected to be a very important step in the development of the laser. This new type of light source is expected to be a very important step in the development of the laser.

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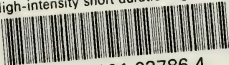
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